# Belief Beyond Causal Interaction

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**Abstract**

Scientific realists offer different accounts of when it is rationally warranted to believe in the existence of entities postulated in science. Some argue that in order to avoid speculative metaphysics, the epistemic line must be drawn at the point of causal interaction, yielding beliefs about the entities we are causally connected with in a particular way. Others claim that explanatory power is enough to warrant belief, and that we ought to accept the existence of whatever entities that best explains our observations. The distinction between explanationists and what we may call 'detectionists' can be illuminated by considering the evidence and reasoning permeating many cases in astronomy and cosmology. In this paper, I present two such cases that disfavour the detectionist account of normative belief and favor the explanationist. Cosmology and astronomy provide a rich scientific context in which we can test the plausibility of accounts for rational belief given by philosophers of science. I argue that the account of rational belief given by detectionism is made implausible when applied in this context.

## 1 Introduction

Philosophers of science disagree about where to draw the line regarding which theories one ought to believe are true, and/or which entities one ought to believe exist. In the scientific realist camp, Psillos defends the idea that inference to the best explanation "is the kind of inference which authorises the acceptance of a hypothesis H as true, on the basis that it is the best explanation of the evidence." (Psillos 2009, 68) In Psillos' general account of realism, the so called 'Divide et impera' approach, he restricts the legitimacy of truth-inferences to entities associated with predictive empirical success. This means that if part of a theory is indispensable for the predictive success of the theory, we may infer the (approximate) truth of that part, precisely because the best explanation for its predictive success is its truth. This condition for belief is by and large shared by Kitcher (2001):

> Instead of thinking about the virtues and vices of whole theories, we should distinguish the hypotheses that are genuinely put to work, claiming that the success of a theory provides grounds for thinking that those hypotheses - the hypotheses that characterize "working posits" - are approximately true. (Kitcher 2001, 170)

Because of the epistemic emphasis given to the explanatory connection between success and truth, the position held by Psillos and Kitcher is sometimes referred to as explanationism. Realists with more modest ambitions have worried about the possible metaphysical

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inflation that the explanationist approach might bring to scientific beliefs and have instead adopted a more conservative strategy for belief. Two realist views that arguably aims for a more conservative approach is the 'semi-realism' offered by Chakravartty (2007), and the 'theoretical irrealism' forwarded by Azzouni (2004). Both philosophers have an essentially realist view, but take precautionary steps with respect to the epistemology of scientific realism. The epistemology championed in these views centers around causal contact, where belief in the existence of an object of scientific study is premised on the causal interaction with that object. Chakravartty makes an epistemic distinction between what he calls *auxiliary properties*, defined as the properties which a theory ascribes to a theoretical entity, and *detection properties* defined as "the causal properties one knows, or in other words, the properties in whose existence one most reasonably believes on the basis of our causal contact with the world." (Chakravartty 2007, 47) He assigns a demarcation criterion in order to distinguish between auxiliary properties and detection properties based on instrumental interaction to the world via causal processes. Azzouni (2004) employs a similar line of reasoning, but argues at more length that extending entity-realism beyond observables is justified because instrumental interactions share the relevant epistemic properties of observation. In virtue of the epistemic emphasis given to the causal detection of objects I will refer to the position held by Chakravartty and Azzouni as *detectionism*.

In this paper, I argue against detectionism. I present two arguments based on the evidence and reasoning found in astronomy and cosmology which show that it is reasonable to believe in the existence of some objects despite lacking the causal contact that detectionism premises belief on. The paper is disposed as follows. I start by making a some preliminary remarks with respect to the approach of letting scientific results inform philosophical doctrines. Section 3 explicates the view I call detectionism, and its particular formulation given by Azzouni. The first argument against this view is given in section 4 and focus on the cosmic event horizon and the epistemic status of objects crossing it. Since the cosmic event horizon marks a causal boundary, detectionism implies that we should instantaneously stop believing in the existence of an object at the time the objects crosses the horizon. I argue that there is good reason to reject such an epistemology. The detectionist account also struggles to make sense with respect to objects the light of which has not yet reached us. The second argument against detectionism focus on the nature of the evidence and reasoning for the existence of dark matter given by cosmologists and astronomers. I outline some of the most well-known and salient evidence used to support the existence of dark matter and show that none of the evidence is compatible with the detectionist condition for belief. This argument constitutes section 5. In section 6 I argue that an explanationist is much less troubled by these results in cosmology. Section 7 concludes.

## 2 Scientifically informed realism

I want to make some preliminary remarks that I hope can help serve to dissipate any skepticism about the idea that scientific results can, or even should, inform philosophical doctrines about those very results.

Since the aim of the paper is to argue that one particular version of scientific realist epistemology surpasses another, one could worry about exactly how specific scientific results can bring to bear on such an aim. Realism, after all, is supposed to guide rational commitment with respect to those results, not the other way around. Any criticism against a philosophical view would be expected to origin from philosophical argument - perhaps a logical inconsistency or a reductio - as opposed to the scientific results which are the very object of study for those philosophical views. Following Azhar and Butterfield (2017), I argue that case-studies of particular scientific results (and reasoning) can have rich philosophical implications. Throughout the history of science the implication of theoretical and experimental results have greatly outstripped philosophical imagination, providing pressure on philosophers to reevaluate epistemic claims about the nature of evidence, its relation to specific hypotheses, our epistemic access to the world and so forth.[1] Cosmology is a scientific study that lends itself well to provide precisely this sort of pressure. In cosmology, we find extraordinary claims of knowledge about fundamental questions such as the origin and evolution of the universe or the nature of space and time (or spacetime). Surely, such claims should prompt us to consider how cosmologists can *know* about such matters. As an example of how cosmology can impact philosophical views, Azhar and Butterfield (2017) argue that:

> [C]osmology threatens the usual philosophical distinction between (i) under-determination by all data one could in principle obtain, and (ii) under-determination by all data obtainable in practice, or up to a certain stage of enquiry. [...] For data about the early universe is so hard to get that what is not obtainable in practice looks very much unobtainable in principle! (Azhar and Butterfield 2017, 10)

In this spirit, I see it as both a reasonable and interesting endeavor to investigate which scientific claims that latch on to realist epistemologies, and assess possible divergences between what cosmologists claim to know, and what realists claim that one ought to believe.

## 3 Detectionism and instrumental interactions

As we saw, Chakravartty's semi-realism distinguishes between auxiliary and detection properties, where only the latter are candidates for belief. He relies on causality to provide the epistemic connection between them and us:

> The realist requires a practical means of demarcating detection properties (and the structures associated with them) from auxiliary properties. Here is a suggestion. Detection properties are connected via causal processes to our instruments and other means of detection. (Chakravartty 2007, 48)

This modest approach towards a realist epistemology is also present in Azzouni's account, which involves believing in objects which we have what Azzouni calls 'thick epistemic access' to. Thick epistemic access is argued to be a sufficient condition for belief in theoretical entities. This is contrasted by the notion of 'thin epistemic access', a kind of Quinean confirmational holism where the existence of stipulated objects in a theory are confirmed when the theory as a whole is confirmed. Thick epistemic access is defined such that "[t]he epistemic processes, which establishes truths that we're committed to, must be sensitive to the objects *about which* we're establishing those truths" (Azzouni 2004, 372). Thick

[1] Standout examples include how the emergence of quantum mechanics impacted Leibniz Principle of the identity of indiscernibles (see French and Redhead (1988) and Butterfield (1993)), as well as how the limits of empirical enquiry in high energy physics can lead to reassessing the epistemic role of non-empirical theory assessment (see Dawid et al. (2015), Dawid (2016, 2017)), or how experimental practices can shape epistemology with respect to science (see Evans and Thebault (2019)).

epistemic processes then have to satisfy a sensitivity condition, a condition Azzouni calls the 'tracking requirement'. The process essentially has to track the relevant objects over time. While he takes observation to be the most obvious epistemic process that satisfies the tracking requirement, he argues that instrumental interactions does as well. Since the salient epistemic traits of instrumental interactions are the same as the epistemic traits that observation have, they are thereby able to license belief about objects accessible through such interactions. In other words, instrumental interactions can be thick epistemic processes which satisfy the tracking requirement. Azzouni claims that the relevant relation by which we establish knowledge via instrumental interactions is causation, by virtue of it being the most reasonable process by which we establish relations of sensitivity:

> [...] for macro-objects like ourselves, the only respectable tool to satisfy the tracking requirement is the cognitive grasping of properties of objects by causation of some sort - sensitivity to objects must be due to a physical operation of those objects (or of things which those objects have affected) on us. (Azzouni 2004, 374)

The normative verdict on whether or not we ought to believe in the existence of theoretical entities will thus depend on the nature of the epistemic process through which the evidence is gained with respect to the offered normative conditions. But which epistemic features does Azzouni claim that observation and instrumental interaction share? For any process to be epistemically privileged it must be the case that it:

> (1) reveals properties that upset our (theoretical) expectations; further, what instruments detect greatly outstrips what theories predict about this; (2) involves autonomous - theory-free - means of adjusting and refining instruments and what they reveal; (3) allows monitoring over time, and (4) allows a study of how the instrumental assess to items reveals properties of what's being studied. (Azzouni 2004, 383-4)

Since these features are not sui generis for observation, whatever epistemic process that shares these salient features will be equally epistemically privileged. One such process, Azzouni argues, is instrumental interactions in science, so if we ought to believe in the things we observe because observation has a set of particular epistemic features, then we ought to believe in the objects that instrumental interaction detect for the very same reasons:

> For instrumental interactions with theoretical objects [...] have the same four aspects that observation has. We can take the theoretical entities (which we have epistemic access to) to be real for the same reasons and on exactly the same grounds as we can take observational entities to be real. (Azzouni 2004, 383-4)

At this point, I want to disperse two possible worries about Azzouni's use of causality. One could worry about the fact that Azzouni's account focus on causal interactions with *theoretical* objects. Sometimes, theoretical is taken to mean non-empirical, in which case causal interaction with such objects would be impossible. However, we may simply interpret Azzouni charitably and say that an object is theoretical in so far as its nature and description is given by the theoretical framework in which it is embedded. Such an interpretation does not exclude possible causal interactions with theoretical objects, but it does not guarantee it either. Azzouni is also unclear with respect to the kind of causal interactions that we may use in order to gauge which objects we can believe are real. Should we take interactions to mean processes which involve manipulability, or perhaps intervention? Since Azzouni's account is meant to defend a restricted form of entity realism (and therefore theoretical irrealism), one might be tempted to think about these interactions as Hacking (1983) does, which has famously become the slogan of entity realism: "[s]o far as I'm concerned, if you can spray them then they are real. [23]" While this approach seems perfectly defensible with respect to instrumental interactions with (certain) microphysical objects, it's obviously not a feasible method for instrumental interactions with large scale systems such as galaxies, nebulae, quasars, black holes and the cosmic microwave background. There is no spraying of these objects. Clearly, it is not reasonable to use this account in order to flesh out Azzouni's causal condition. What about an interventionist account? Alas, this view on causality would struggle to establish causal relations between observers and large scale systems. We simply cannot intervene with large scale systems millions of miles away. One way to circumvent such issues is to employ counterfactuals with respect to the possibility of interventions:

> [W]hat is crucial is not whether the antecedent of the relevant counterfactual is nomologically or physically possible but rather whether we are in possession of well-grounded scientific theories and accompanying mathematics that allow us to reliably answer questions about what would happen under the supposition of such antecedents. We count interventions as "possible" as long as this is the case. (Woodward (2016))

If we are to invoke theory in order to establish the truth of such counterfactuals, this move is clearly theory-dependent, and as such not suitable for establishing the kind of account of instrumental interactions that is needed in this context. We cannot refer to theory to establish what should be taken to be instrumental interactions if the instrumental interactions are what we are supposed to be using in order to circumvent theory-dependence in determining in what entities we ought to believe.[2] While it's unclear which account of causality that best suits Azzouni, we may put this issue aside and simply understand his view of causal interaction in a more commonsense fashion. Instrumental interactions can be understood in terms of a causal chain that leads from the measured scientific object to the measuring device. So long as there is a causal chain between object and instrument, information about that object is possible and we can take such objects to be real. Now that we have made the detectionist position clear, the next two sections will show that detectionism fails to provide a satisfying epistemology when applied to cases in astronomy and cosmology.

## 4 Horizons and the Hubble sphere

One way in which the detectionist model fail is when applied to objects in space that we can know about, but from which we nevertheless cannot gain causal information. Much of the

[2] Another aspect in which instrumental interactions might be theory-dependent has been suggested by Psillos (2009, 87): "What are really observed in relatively sophisticated scientific contexts (e.g., in the context of an experiment) are not the phenomena themselves but data. [...] Strictly speaking, observations are of data." In the context of observational astronomy, the data might consist of lines in the spectrum of electromagnetic radiation obtained by, for example, the Hubble telescope, which are then sorted and converted into data-sets based on models. The data-sets can then be used to construct the fantastic images of galaxies and nebulae that the Hubble telescope is known for.

background in the following argument is based on work by Davis and Lineweaver (2004).

In cosmology there are a number of different 'horizons' - descriptions of boundaries in spacetime fixed by certain variables - associated with the expansion of the universe.[3] Ever since Friedmann and Lamaître's solutions of Einstein's field equations implied a dynamical universe, which was subsequently confirmed by observations by Hubble and Slipher, we have known that the universe is expanding. As a consequence of this expansion the frequency of light emitted from distant objects, which takes a long time to reach observers, will have changed due to the fact that space itself has expanded during that time. This change of frequency due to the expansion of space is known as cosmological redshift since the light emitted from receding objects have shifted to red. The observational measure of redshift is given by the relation between the emitted wavelength and the observed wavelength:

$$z = \frac{\lambda_{obs} - \lambda_{emit}}{\lambda_{emit}} \tag{1}$$

In the standard model of cosmology, the ΛCDM model, any object where $z > 1.46$ has a receding velocity greater than the speed of light. Receding velocity is commonly not thought of as proper velocity since the value of $z$ is not given by objects strictly speaking moving away from each other, but from the fact that space is expanding in between objects.[4] A horizon, then, is a measure of distance based on the speed of light and a time-interval. The particle horizon is defined by the maximal distance that a photon can have travelled between $t = 0$ and any given time ($t$). The event horizon is the maximal distance that a photon can travel between a given time ($t$) and $t = \infty$. Given that there are objects with a redshift, $z$, greater than the speed of light, this should imply that light emitted from such objects can never reach us, and therefore, by detectionists lights, we ought not to believe in the existence of such objects. This, however, is not necessarily so.

We can take the total velocity of light ($v_{tot}$) to be the velocity of recession ($v_{rec}$) plus its local peculiar value ($c$). If $v_{rec} > c$, this should imply that the total velocity of light is negative, i.e "moving" away from us. We can, however, use Hubble's law ($v_{rec} = HD$) to define the sphere beyond which objects recede with a velocity greater than the speed of light as:

$$D_{HS} = \frac{c}{H} \tag{2}$$

In models where $D_{HS}$ increases with time, light can still reach us so long as the recession velocity of the Hubble sphere is greater than the value of the total velocity of the light. Light emitted by objects receding faster than $c$ can therefore reach observers when $D_{HS}$ has expanded enough to include that light in its subluminally expanding domain:

> In decelerating universes $H$ decreases as $\dot{a}$ decreases (causing the Hubble sphere to recede). In accelerating universes $H$ also tends to decrease since $\dot{a}$ increases more slowly than $a$. As long as the Hubble sphere recedes faster than the photons immediately outside it, $\dot{D}_H > v_{rec} - c$, the photons end up in a subluminal region and approach us. Thus photons near the Hubble sphere that are receding slowly are overtaken by the more rapidly receding Hubble sphere. (Davis and Lineweaver 2004, 105)

[3] Even though event horizons may primarily be associated with black holes, which is another example of a causal boundary, they are not sui generis for black holes.

[4] Since the relative "motion" of objects with $z > 1.46$ is not in any observers inertial frame, the fact that some galaxies have recession velocities greater than the speed of light does not violate special relativity.

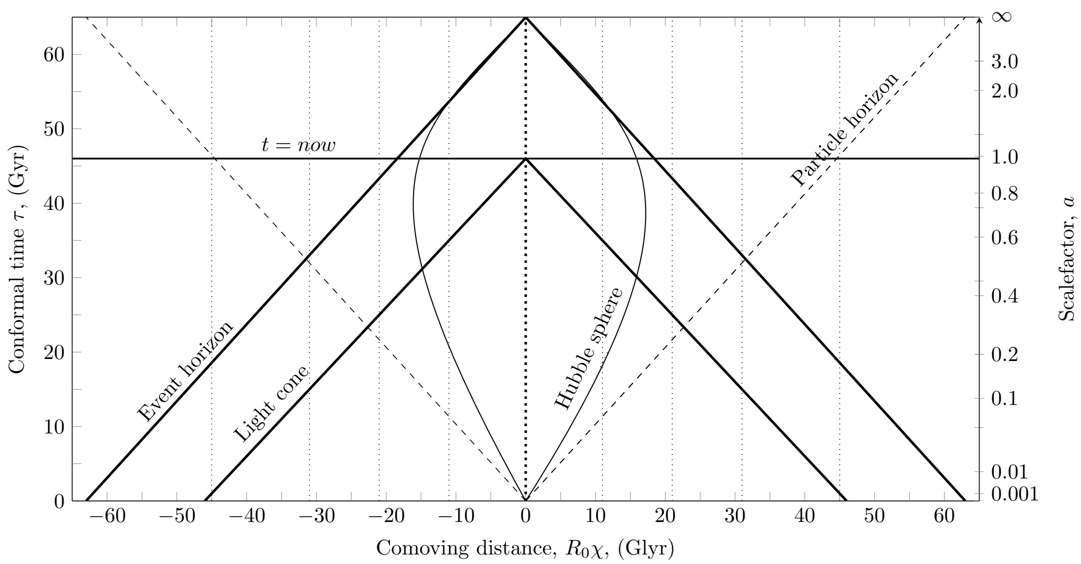


Figure 1: Spacetime diagram of the expansion of the universe based on the cosmic standard model ΛCDM ($\Omega_M = 0.3, \Omega_\Lambda = 0.7$, and $H_0 = 70km/s^{-1}Mpc^{-1}$) and General Relativity. Centered vertical thick dotted line shows our worldline, paralell thin dotted lines show worldlines of comoving objects. Comoving objects outside of the Hubble sphere has $v_{rec} > c$. Currently (t=now) observable events are inside the light cone, ∼ 46 Gyr away, which is also the current distance to the particle horizon. Diagram reconstructed based on Davis and Lineweaver (2004).

This allows us to make two interesting points against the detectionist. The first is that there must be objects which have emitted light that has not reached us yet, given that the light is currently in a region of space receding superluminally (that is, at a velocity $> c$), but that eventually will reach us. The second is that, since the distance to the objects emitting that light increases, so does their recession velocity, meaning that light emitted from them today will never reach us. What does this imply for detectionism? Regarding the first point, should we already believe that there are such objects, or should our belief in them be suspended until its light reaches us? Since the light is the first ever causal contact we have with the object, the natural interpretation from a detectionist point of view is the latter. The latter option, however, is incompatible with the second point. At the time when information, in the form of light, about a receding object reaches us, detectionism says that we in fact should *not* believe that the object that emitted the light exists, since at this point, that object has crossed the event horizon. If it has crossed the horizon this means that we can never come in causal contact with it, which ultimately, according to the detectionist view, implies that we should suspend our belief in its existence. On this view, such objects are not really objects, but merely images of non-existing objects. In a sense, such objects are ghosts. And we shouldn't believe in ghosts. Perhaps detectionists would argue that what we should believe is that such objects *have* existed in the past, that is, at the time they emitted their light - there is no need to speculate about whether those objects still exist today. This has a rather peculiar implication for galaxies that cross the event horizon:

> Most observationally viable cosmological models have event horizons and in the ΛCDM model, galaxies with redshift $z \sim 1.8$ are currently crossing our event horizon. These are the most distant objects from which we will ever be able to receive information about the present day. The particle horizon marks the size of our observable universe. It is the distance to the most distant object we can see at any particular time. The particle horizon can be larger than the event horizon because, although we cannot see events that occur beyond our event horizon, we can still see many galaxies that are beyond our current event horizon by light they emitted long ago. (Davis and Lineweaver 2004, 101)

This means that everyday, we ought to reduce the number of galaxies we believe exists, since, for every passing day, the number of galaxies which we can receive information from decreases.[5] There is no reason to expect these galaxies to suddenly collapse or vanish simply because we cannot longer receive information from them, but it is nevertheless what detectionism implies. It continuously and instantaneously revise the epistemic status of galaxies crossing the event horizon by shifting belief in them from existing to non-existing (or have existed). Surely, this is not a reasonable epistemic stance towards such objects.

# 5 Dark matter

The case of dark matter can provide an additional context of evaluation with respect to detectionist epistemology. Looking at the evidence given for the existence of dark matter should provide us with clear answers from detectionists regarding whether or not we ought to belief in its existence. A complete review of the evidence given to support the existence of dark matter lies beyond the scope of this paper, but a brief overview of the evidence usually invoked for its existence suffices to bring out the nature of the evidence, enabling a normative assessment. I will largely follow the canonical description of the history of dark matter as given by Bertone and Hooper (2018).

## 5.1 Galaxy rotation curves

Even though Zwicky's measurements of the coma cluster already in the 1930's revealed a high mass-to-light discrepancy which he explained by postulating 'dunkle materie', the discrepancy, and its explanation, was only taken seriously after Rubin's measurements of the Andromeda galaxy. In the 1970's, Rubin and Ford Jr (1970) used an image tube spectograph built by Ford in order to make observations of the Andromeda galaxy. 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 decreases with distance so that planets close to the sun orbits faster than planets further away. When analyzing the rotation curve of 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. A consequence of flat rotation curves is that with the speed measured, the gravity from the luminous

[5] In dark energy dominated models, given enough time, we should not believe that there is anything beyond the milky way. This is because space keeps expanding between, but not within, all gravitationally bound objects.

mass in galaxies is not enough to keep it together. Much work on the rotation curves of galaxies followed, and 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 radius, showing that the mass-to-light discrepancies in galaxies were systematic. 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". Bertone and Hooper (2018) writes that "a consensus [...] began to to emerge in favor of dark matter's existence"[57].

## 5.2 Gravitational lensing

Gravitational lensing is the physical phenomena produced by:

> [...] the deflection of photons as they pass through the warped space-time of a gravitational field. Light rays from distant sources are not "straight" (in a Euclidean frame) if they pass near massive objects, such as stars, clusters of galaxies or dark matter, along our line of sight. (Massey et al. 2010, 3)

As the quote indicates, one kind of evidence for dark matter comes from measuring the effects of gravitational lensing by galaxies and galaxy clusters. Clowe et al. (2006) used weak gravitational lensing observations of the Bullet cluster as evidence of the presence of dark matter. The Bullet cluster consists of a pair of colliding galaxy clusters, and as a result of the collision, the matter distribution in the region had been altered, spatially separating the hot X-ray emitting gas within the clusters from their stars and planets. The majority of the baryonic matter in the system was now present in the gas, which enabled the team to directly compare the Bullet cluster's baryonic distribution with the location of its gravitational potential. They found that the location of gravitational potential of the system did not correspond with the location of its baryonic mass.

## 5.3 Large structure formation

Measurements of the cosmic microwave background (CMB) has been continuously carried out since its discovery in the 1960's by Penzias and Wilson. With 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. From careful analysis of the data, cosmologists have seen small temperature fluctuations associated with fluctuations in matter-density. Lower temperatures corresponds to higher densities, and higher temperatures to lower densities. The density fluctuations themselves are 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. Since dark matter does not interact electromagnetically, it could exert gravitational influence without being affected by the radiation pressure. At the time of recombination, when free electrons coupled with protons to form neutral hydrogen atoms enabling photons to travel freely, the matter-densities due to these baryonic acoustic oscillations remained in their current state, 'frozen' as it were, providing the initial structure of the matter-distribution we see today in the form of galaxies and galaxy clusters. Without the gravitational influence exerted by (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.[6]

## 5.4 Dark matter and detectionism

How does the evidence that supports the existence of dark matter impact the detectionist account? No instrumental interaction, neither by direct detection, as in the case of the experimental approaches taken by DARWIN and CDMS (Cryogenic Dark Matter Search), nor by indirect detection, as in the case of colliding protons and look for a unique signature of missing energy, an approach taken by ATLAS at the LHC, has been successful. Detectionism appears to give a straight forward answer regarding whether or not we should believe in the existence of dark matter: no. At this point, it is important to not conflate scientific endorsement and realist commitment. Obviously, neither Chakravartty nor Azzouni's account rules out the dark matter hypothesis as a scientific hypothesis that one can endorse. The hypothesis is certainly compatible with the observations and data so there is nothing in their accounts that precludes endorsement. What is at stake is the further claim that we ought to believe that dark matter really exist given that it works so well as a scientific hypothesis. In other words, it is realist commitment, not theory endorsement, that is on the line. With respect to realist commitment, Chakravartty's view states that dark matter must be treated as an auxiliary property which we ought to be either agnostic or sceptical towards. Interestingly, he seems to suggest that auxiliary properties are such that "[f]urther investigations may allow us to detect them, thus converting them into detection properties, or rule them out altogether" ((Chakravartty 2007, 48)).

The present situation with respect to dark matter does not conveniently fit into this categorisation. Dark matter might only ever interact with gravity (or with other particles in the so called "hidden" or "dark" sector beyond the standard model) which would suggest that it might *never* be detectable in Chakravartty's sense, and must therefore permanently be regarded as mere fiction. In that case, we will never be realists about dark matter, no matter how much evidence (of the above kind) that we have for its existence. This result stands in stark contrast to the level of confidence that cosmologists, astronomers, and astrophysicists have in the existence of dark matter. More worrying is the fact that the collected evidence for dark matter can be interpreted as entirely irrelevant for realist belief according to the detectionist view. Should the evidence for dark matter not be regarded as evidence for its existence according to the detectionist account? Azzouni's tracking requirement even seems to discount the CMB as something that we can believe in given that we cannot monitor it over time. Recall that monitoring over time was an epistemic feature of instrumental interaction modelled on observation:

> What's observed can be monitored, either in the sense of detecting what things observed do over time (watching an insect), or in the sense that time can be taken to explore different aspects of them (climbing a mountain). (Azzouni 2004, 383)

It is not clear that the CMB can be monitored in the sense of detecting what it does over time. Firstly, there are issues with respect to what monitoring over time is even supposed to mean in the context of measuring radiation that was emitted over 13 billion years ago. We do have three separate measurements of the CMB, performed by COBE,

[6] What is known as 'hot dark matter' is not compatible with the observed large scale structure since its free streaming length suppresses the growth of small scale structures in the early universe.

WMAP, and the Planck satellite, which could be argued to constitute monitoring over time. However, the level of precision in measurement differs so greatly between the three missions that any differences in the data could not be attributed to changes in the CMB over time. Additionally, it is unclear what the detectionist could make of the data without theoretical interpretation. It may simply be the case that a detectionist sees the CMB as evidence for radiation only. All other conclusions drawn from the data requires theory, which violates Azzouni's second condition: that what instruments reveal must be theory-free. This condition seems to plague other evidential contexts as well. Instrumental access to galaxies to establish flat rotation curves can only yield data of radiation and radial velocities, but any explanation of the dynamics of the galaxy involves General Relativity as a background assumption and an inference to additional matter. The major, or at least most interesting, part of what the observations reveal is thus theory-dependent. The phenomena of gravitational lensing is also intrinsically linked to GR. In fact, physics and astronomy in general posit entities and phenomena that are dependent on both inferences and well-established theory, but surely this does not mean that we could never have good enough evidence to believe in their existence, or worse, that there couldn't possibly be any evidence for their existence.

A possible rejoinder from Azzouni may invoke a line of indirect causal links. The tracking requirement stated that "sensitivity to objects must be due to a physical operation of those objects (*or of things which those objects have affected)* on us". It might be possible, from Azzouni's perspective, to argue that dark matter has had a causal effect on the systems we observe, in which case there is an indirect causal connection between dark matter and our instruments. However, such a move is internally inconsistent:

> [...] to hypothesize a causal connection between theoretical terms and what's referred to is to make a metaphysical claim. Causation thus far belongs to theory - and so if one tells a 'success story' about one's theory and then brings in causal connections that way (as part of our successful theories), or if one invokes causal connections to theoretical entities as on a par with causal connections to observable entities, one has failed to address the opponents epistemically; but their challenges to realism lie in epistemology, not metaphysics. (Azzouni 2004, 390-1)

The claim that we have an indirect causal connection to dark matter via its physical influence on the behavior of baryonic matter due to its gravitational influence on Azzouni's view is to presuppose the connection between the theoretical term and what it refers to. Moreover, no instrumental interactions with dark matter has been made by instruments specifically constructed for this purpose. The instruments that have been used to obtain the data from which dark matter has been inferred are mostly telescopes capable of detecting different parts of the electromagnetic spectrum and spectrometers (although more recent developments include gravitational signals and neutrino detectors), neither of which are directly sensitive to dark matter, so would not be able to track it in the sense required.

## 6 Explanationism and Cosmology

Prima facie, explanationism is largely unaffected by the two arguments considered here. With respect to the evidence given in support of the existence of dark matter, many of the individual evidential situations rely on explanatory reasoning, and the collected evidence displays one of the virtues associated with explanationism - unification. A quick reflection of the evidence is sufficient to substantiate these points. The best explanation for flat rotation curves is the presence of additional matter influencing the dynamical behavior of galaxies. The background assumption for this piece of explanatory reasoning is of course that GR is a correct description of gravity at large scales. In fact, the only other explanation for the phenomena of flat rotation curves is modified Newtonian dynamics, known as the abbreviation MOND, which rejects the background assumption that GR correctly describes gravity in large scale systems. MOND instead replaces $F = ma$ in low acceleration systems with $F = ma^2/a_0$ implying that gravity works differently at different scales. However, in so far as we think that GR is correct, there is no alternative explanation on offer other than that the presence of dark matter alters the dynamics of galaxies with flat rotation curves by influencing spacetime. A stronger argument against MOND is also that it is only an alternative theory to GR with respect to certain domains. While it is an alternative to explaining flat rotation curves, it is not an alternative explanation to dark matter in most other contexts, for example with respect to the Bullet Cluster and large structure formation. In the Bullet Cluster case, MOND is unable to account for the fact that the gravitational potential is decoupled from the baryonic mass. However, if only matter influences spacetime, as GR states, then any distortion of spacetime will be due to the presence of matter, in which case only the existence of additional non-luminous matter can explain the observed gravitational potential in the Bullet Cluster.

The explanatory reasoning invoked within each of these individual evidential cases may serve as indications that the dark matter hypothesis is a viable hypothesis that science ought to pursue, but is it enough to license a genuine realist commitment? It is one thing to say that explanatory reasoning can be used for theory-endorsement, it's quite another to say that it should guide realist commitment, as the scientific realist claim. The situation is somewhat perplexing. In many of the evidential contexts considered, dark matter is the best explanation, which should prompt a realist commitment. It is unreasonable, however, to suggest that a single evidential context is enough to conclusively confirm the existence of dark matter. The main reason for believing that dark matter actually exist is not the explanatory reasoning employed within each evidential context but rather that all the evidence, taken collectively, is so well explained by the existence of dark matter.[7] This, of course, is the well known idea that unification is an explanatory virtue of hypotheses which are true. When asked why to believe that dark matter actually exist, cosmologists and particle physicists invoke precisely the fact that the existence of dark matter not only explains a specific set of data, but a huge variety of data and phenomena.[8] Dark matter unifies several distinct phenomena that other hypotheses simply cannot. As we saw, even when properly formulated relativistically, MOND has only been successful in predicting flat rotation curves for galaxies, but fails to account for the separation of gravitational potential and baryonic matter in the Bullet cluster, mass/light discrepancies in large galaxy clusters, and the large scale structure of the universe. It is the fact that dark matter can explain these distinct phenomena, many of them unknown at the time the dark matter hypothesis became a serious scientific hypothesis, that make scientists so convinced that dark matter really exist. In light of this, the epistemology of explanationism, as compared to detectionism, coheres better with scientific reasoning and is better equipped to deal with the evidence in cosmology and astronomy.

[7]While this is well within the spirit of explanationism, it implies that the epistemic bar for conclusive confirmation is (and ought to be) higher than for realist commitment, which runs counter to realist intuitions.

[8]These answers are compounded from conversations with cosmologists and particle physicists.

## 7 Conclusion

Philosophers of science has sought to provide an account of when we ought to believe in entities postulated in scientific theories. Cosmology and astronomy provide a rich context of scientific theories in which we can test these normative accounts for rational belief. In this paper, I argued that one such account, detectionism, failed to accurately track the objects of rational belief. First, it unreasonably entailed that we ought not believe that galaxies which passes the cosmological event horizon exist since this horizon is a causal boundary. There is no reason to expect these galaxies to suddenly collapse or vanish simply because we cannot longer receive information from them, but it is nevertheless what detectionism implies. Second, it cannot account for the evidence given for dark matter, since this evidence essentially relies on inference given a background theory. No instrumental interaction with dark matter has as of yet been established, which in the detectionist framework means that there is no reason, *pace* cosmologists, to believe that it exist. To disregard the evidence for dark matter as evidence simply because no direct causal contact has been established is an unreasonable epistemology for cosmology and astronomy. A rival account for rational belief, explanationism, was argued to better account for the evidence and reasoning in this context.

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