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# Modest Scientific Realism and Belief in Astronomical Entities

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ABSTRACT. One of the core charges against explanationist scientific realism is that is too epistemically optimistic. Taking the charge seriously, some realists has presented alternative forms of scientific realism – semi-realism and theoretical irrealism – designed to be more modest in their epistemic claims. In this paper, I consider two cases in cosmology and astrophysics that raises novel issues for both views: semi-realism is argued to end up doing metaphysical astrophysics with respect to the existence and evolution of galaxies and other astrophysical objects that cross the cosmic event horizon; theoretical irrealism is argued to be incompatible with standard evidential reasoning in the context of the dark matter problem.

KEYWORDS: Entity Realism, Cosmic Event Horizon, Dark Matter

## 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 is a vivid defender of the idea that inference to the best explanation ”is the kind of inference which authorizes 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, 170). Because of the epistemic emphasis given to the explanatory connection between predictive success and truth, the position held by Psillos and Kitcher is often referred to as explanationism. Some philosophers worry that the epistemology of explanationism is too permissible in light of objections like the pessimistic meta-induction (Laudan, 1981; Lyons, 2006). Those philosophers have prompted a more conservative strategy to delineate rational belief. Two realist views that arguably aim 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 and instrumental interaction, where belief in the existence of an object of scientific study is premised, in some way, on the causal interaction with that object by instrumentation. 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 address two overlooked scientific contexts in which the consequences of the central tenets of detectionism is opaque, and therefore in need of clarification: the case of the cosmological event horizon, and the dark matter hypothesis.

## 2. Scientifically informed realism

Since the aim of the paper is to put pressure on one particular version of scientific realist epistemology given the epistemic grounds for belief in certain scientific theories held by scientists, one may reasonably worry about exactly how specific scientific reasoning can bring to bear on such an aim. Realism, after all, is supposed to guide rational commitment with respect to science, not the other way around. From this perspective, any criticism against a philosophical view like scientific realism would be expected to origin from philosophical argument – perhaps a logical inconsistency or a reductio – as opposed to the scientific processes 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, and should, 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. Standout examples include how the emergence of superposition in quantum mechanics impacted Leibniz Principle of the identity of indiscernibles (see French and Redhead (1988) and Butterfield (1993)), how the limits of empirical inquiry in high energy physics can lead to reassessing the epistemic role of non-empirical theory assessment (see Dawid et al. (2015); Dawid (2016, 2017)), and how the experimental practice of analogy in physics can shape epistemology with respect to science (see Evans and Thebault (2020)). 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 is reasonable to believe, and what realists claim that one ought to believe. In addition, philosophy of science in general, or scientific realism in particular, must essentially be informed by science as a whole. This includes not only experimental practices, the interpretation of data, the construction of hypotheses or theory confirmation but also scientific reasoning. It is part of the job and scope of philosophy of science, and therefore scientific realism, to represent and model scientists trust in their theories. If it doesn't, it digresses from being a philosophy of *science* properly understood.

## 3. Detectionism

### 3.1. Chakravartty's account

Chakravartty's semi-realism is an explicit attempt at making the idea of scientific realism more epistemically safe against objections like the pessimistic meta-induction, underdetermination by data and challenges to inference to the best explanation. His specific position aims to take the idea of selective scepticism – to not accept predictively successful theories wholesale – and pair it with the dictum that "a realist's degree of belief should reflect one's degree of causal contact, with mastery and manipulation at one end of the spectrum, and mere detection and weaker speculation at the other". (Chakravartty, 2007, 47) It is clear that causality plays the main role here, setting the parameters for rational belief and guiding realist commitment according to the level of strength of causal contact. Chakravartty continues to flesh out his semi-realism by distinguishing between auxiliary properties and detection properties, where only the latter are candidates for rational belief. Auxiliary and detection properties are described, and distinguished, as follows:

> An auxiliary property is one attributed by a theory, but regarding which one has insufficient grounds, on the basis of our detections, to determine its status. (Chakravartty, 2007, 47)

And;

> 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)

Causality does much (all?) of the heavy lifting in order to provide an epistemically safe connection between the detection properties of scientific objects and us. Knowledge about these properties, and their relations, are then thought to constitute knowledge about concrete structures of the world – objects and entities – which then furnishes the ontology of particulars in semi-realism. (Chakravartty, 2007, 64)

### 3.2. Azzouni's account

Azzouni's 'theoretical irrealism' involves reasonably believing in the existence of objects which we have 'thick epistemic access' to. Thick epistemic access is argued to be a sufficient condition for belief in unobservable 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 epistemic processes then have to satisfy a sensitivity condition – the 'tracking requirement' – such that the process has to track relevant objects over time. The general idea is to take the epistemic features associated with the reliability of ordinary observation and show that these features are in fact also present in instrumental interactions. Since the salient epistemic features of instrumental interactions are the same as the epistemic features of observation, they are thereby able to license belief about objects accessible through such interactions. 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 [...] (Azzouni, 2004, 374)

The normative verdict on whether or not we ought to believe in the existence of an entity depends on the nature of the epistemic process through which the evidence is gained with respect to the offered normative conditions. The relevant epistemic features are such that they:

> (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 epistemic features are essential of observation, whatever epistemic process that shares these features will be equally epistemically privileged. Azzouni's claim is that instrumental interactions in science do. This means that 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 [...] 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)

Even though Azzouni makes use of causation, it's not the central point in his account. The core of his point is that once one reveals what the salient epistemic properties in observation are, we have a basis for evaluating if these properties can be found in other methods as well.

## 4. Semi-realism and the cosmic event horizon

Astronomers, cosmologists and astrophysicists claim that there are objects in space that we can know about, but from which we nevertheless cannot gain causal information. What are these claims, and how can they be understood in Chakravartty's semi-realism? Much of the background in the following argument is based on work by Davis and Lineweaver (2004).

In cosmology, astronomy and astrophysics it is commonplace to accept that there are 'horizons' – descriptions of causal boundaries in spacetime – associated with the expansion of the universe. 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 will have changed due to the continuing expansion of space. This change of frequency due is known as cosmological redshift, aptly named because the light emitted from receding objects shifts to red. The observational measure of redshift ($z$) 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 $\Lambda$CDM model (where $\Lambda$ is dark energy and CDM Cold Dark Matter), 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.[1] 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 traveled 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, given the focus on causality in semi-realism, we ought not to believe in the existence of such objects. This, however, may not necessarily be 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

[1] 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.

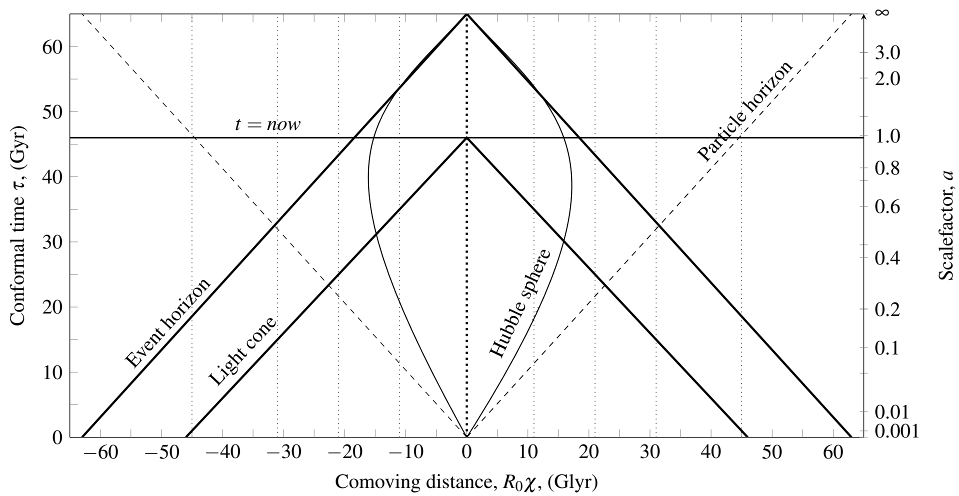


FIG. 1: *Spacetime diagram of the expansion of the universe based on the cosmic standard model ΛCDM ($\Omega_M = 0.3, \Omega_\Lambda = 0.7$, and $H_0 = 70 km/s^{-1}Mpc^{-1}$) and General Relativity. Centered vertical thick dotted line shows our worldline, parallel thin dotted lines show worldlines of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

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)

This allows us to consider two specific cases and what semi-realism may say about them. 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 given the expansion of the Hubble sphere. 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 semi-realism say about such objects? Regarding the first case, should we already believe that there are such objects, or should our belief in them be suspended until their light reaches us? Since the light is the first ever causal contact we have with the object, the natural interpretation from a semi-realist perspective is the latter. That is to say, we should not believe in specific objects that we have not yet detected, despite having good theoretical reasons to do so. It is only once the light reaches us and establishes a causal connection that belief in the object that emitted the light is warranted. This option, however, may be hard to resolve given the second case: at the time when information, in the form of light, about a receding object reaches us, semi-realism may be interpreted as saying 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 semi-realist view, implies that we should suspend our belief in its existence. Rational belief was supposed to be guided by the spectrum of causal contact, where manipulation was the gold standard, but these astronomical objects fall outside of our causal reach by definition.

While we might be able to detect a galaxy using optical and radio telescopes, the problem for semi-realism is that the light emitted from this galaxy, the light which is detected, is so old that at the time it has reached observers, the galaxy itself is beyond the event horizon. Given that the event horizon explicitly mark a causal boundary, it is by definition not detectable any longer. The strange consequence for semi-realism may be that we have detected what should be considered an undetectable object. Chakravartty's (2007, p.14) definition of 'undetectable' as "unobservables one cannot detect at all" fits the situation perfectly. Should such objects be considered images of non-existing objects? Are their properties auxiliary? Semi-realists could perhaps argue that what we in fact 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 response has a rather peculiar implication for galaxies that cross the event horizon:

> Most observationally viable cosmological models have event horizons and in the $\Lambda$CDM 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)

For semi-realism this could mean that we ought to continuously reduce the number of galaxies that we reasonably believe exist, since, for every passing day, the number of galaxies which we can receive information from in the form of light decreases. If no viable cosmological model entails that causal contact with objects crossing the event horizon at time $t_{now}$ can be established, this ought to mean that we have no reason to believe in the continued existence of those objects. This is because there is no possible time after $t_{now}$ in which we can causally connect with that object. Should the properties of galaxies passing the cosmic event horizon be considered to be auxiliary properties or detection properties? Even though we can establish a causal connection to a past version of that object, that is at some time before $t_{now}$, $t_{now}$ marks something like an expiration date on the properties to count as causal. The properties are by definition no longer causally accessible to us, so they ought not be considered candidates for being detectable. The properties of such galaxies ought instead, by virtue of the expansion of space alone, be considered auxiliary, because they from that point on only can be attributed by theory alone. Recall Chakravartty's definition of auxiliary:

> An auxiliary property is one attributed by a theory, but regarding which one has insufficient grounds, on the basis of our detections, to determine its status. (Chakravartty, 2007, 47)

Things get even more tricky in dark energy dominated models. This is because space keeps expanding between, but not within, all gravitationally bound objects, meaning that we, given enough time, will be left causally connected with objects gravitationally bound to the Milky Way or the local group. Is the implication that future generations, should they subscribe to semi-realism, ought not believe that there exists anything beyond our gravitationally bound neighborhood? Despite having no good reason to expect objects that recede beyond a causal horizon to change because we cannot longer receive information from them, it is unclear how semi-realists can avoid this implication given their emphasis on causal contact. Since we have good theoretical reasons to think that the same laws of physics govern the universe even beyond the event horizon, this implication is something that semi-realists need to clarify. Semi-realism states that auxiliary properties can convert into detection properties and therefore be retained in succeeding theoretical frameworks – this was in fact one of the selling points of semi-realism in arguing against the pessimistic meta-induction – but here, the situation is reversed: detection properties are converted, by no known physical process, into auxiliary properties. Perhaps semi-realists can be interpreted more favorably and say that so long as an object has been detected once, belief in that object is warranted. A consequence of such an objection in the context of the above argument would of course be that we in fact *can* have warranted rational beliefs about objects that by definition are beyond our causal reach, which violates the whole rational of semi-realism.

## 5. The Evidence for dark matter

The case of dark matter provides a different interesting context of evaluation of detectionism, this time regarding Azzouni's theoretical irrealism. When examining, even briefly, the evidential situation of the dark matter hypothesis in light of Azzouni's account, one discovers a discrepancy in what ought to count as evidence between scientists and theoretical irrealists. Scientist engage with the dark matter hypothesis in various ways: cosmologists view it as an indispensable part to explain how the universe has evolved; astronomers and astrophysicists use it to explain the dynamics of galaxies and galaxy clusters. While complete convergence on the probability of the existence of dark matter given the evidence is lacking, most scientists display a high level of confidence in its existence.[2] A brief overview of the evidence usually invoked for the existence of dark matter suffices to bring out the nature of the evidence to which we can apply Azzouni's theoretical irrealism. I will largely follow the canonical description of the history of dark matter as given by Bertone and Hooper (2018).[3]

### 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. 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 mass in galaxies is not enough to keep it together.

### 5.2. 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-

[2] For a critique of this confidence and a defense of the MOND (Modified Newtonian Dynamics) alternative to dark matter, see Merritt (2021a,b).

[3] For an in depth account of the nuances and intricacies that the history of dark matter offers see de Swart et al. (2017); de Swart (2020).

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.[4]

### 5.3. Dark matter and theoretical irrealism

How does the evidence that scientists take to support the existence of dark matter fit into theoretical irrealism? No instrumental interaction, neither by direct detection, as in the case of the experimental approaches taken by for example DARWIN and CDMS, nor by indirect detection with ATLAS at the LHC, has been successful. No process has been able to establish a 'thick' connection with dark matter. Prima facie, this ought to mean that, pace scientists, we are not licensed to reasonably believe that dark matter exist. At this point, it is important to not conflate scientific endorsement and realist commitment. Obviously, Azzouni's account does not rule 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 that precludes endorsement. What is at stake is the further claim that we have reasons 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. Having high confidence in a theory and being a realist about what that theory says exist

[4] 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.

are two separated matters, and the theoretical irrealist may simply respond by stating that all is as it should be. It is precisely the point of a modest scientific realist to be cautious when scientists are confident – this is the lesson given by the pessimistic meta-induction – so the fact that theoretical irrealism denies taking dark matter to exist for explanatory reasons is not a problem, it is a virtue. The central point here, however, is not centered around the discrepancy in the acceptance of dark matter as real, but rather in the discrepancy of the acceptance of what ought to be counted as evidence for its existence.

### 5.4. Interpreting the evidence

Recall two of Azzouni's four properties for instrumental interactions to have thick epistemic access to an object:

> [...] 2) involves autonomous - theory-free - means of adjusting and refining instruments and what they reveal; (3) allows monitoring over time [...] (Azzouni, 2004, 383-4)

Here, Azzouni fleshes out the second property (in the context of observation):

> There are (autonomous) means of adjusting and refining observations – one can move for a closer look, for example, or squint. By 'autonomous', I mean that these methods are learnt and executed in ways largely independent of our theories about our senses; we practice navigating by our senses, and not by applying theories about how our senses. (Azzouni, 2004, 383)

Property (2) appears especially conspicuous in the context of evaluating observed phenomena as *evidence* for dark matter. Take the CMB for example. It is unclear what we could make of the data collected by LFI (Low Frequency Instrument) and HFI (High Frequency Instrument) detectors on board the Planck satellite without using a host of theories, both in constructing the instruments themselves, but even more so when interpreting the data. The instruments used to detect the redshifted radiation from the early universe does not reveal much at all when stripped of its theoretical context. There can be no autonomous method of refining the observations because the theory of the objects detected (photons) is also used in the construction of the instruments – optics.[5] In drawing inferences from the data it is essential to use theory, for example general relativity. The interpretation of the small temperature fluctuations found in the CMB are due to fluctuations in gravitational potential, a discovery that rewarded George Smoot and John Mather with the Nobel prize in physics 2006. (Smoot et al., 1992; Mather et al., 1990)

In the other evidential contexts, regarding what the instruments reveal, inferences and theories abound: for example, instrumental access to galaxies to establish flat rotation curves can only reveal data consisting of radiation and radial velocities, but in order to say anything regarding the dynamics of the galaxy again involves general relativity as a background assumption and an inference to additional (dark) matter. The main part, or at least the most interesting one, of what these observations reveal is thus theory-dependent. The phenomena of gravitational lensing is also intrinsically linked to general relativity. In fact, astrophysics 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 should discount such scientific reasoning and inference as evidence? Even if we grant that, from a philosophical standpoint, we, *pace* a large portion of scientists, ought to be cautious with respect to being realist about dark matter, the risk aversion displayed by theoretical irrealism has an unreasonable impact regarding what we ought to count as *evidence* for dark matter.

There is no question that the evidence for the existence of dark matter is considered strong, so it is strange, even despite the epistemic modesty pursued in theoretical irrealism, that the epistemic significance of this evidence should be taken as weak. The result of applying theoretical irrealism to the evidence for dark matter stands in contrast to the level of confidence that cosmologists, astronomers, and astrophysicists have qua the evidence. This isn't to say that we ought to accept a principle which states that we ought to be realists about whatever theories that scientists have confidence in, regardless of their reasons. The point is that scientific realism should be sensitive to scientific reasoning with respect to interpreting what evidence is and how it relates to theory. A scientific realism that fails to recognize the evaluation of what ought to be considered evidence for a theory given by leading scientists in the field should take this as an indication that their epistemology has flaws, and as an opportunity to reflect and

[5] See Tauber et al. (2010) for the theoretical underpinnings of the Planck satellite.

fine tune their position. While the efforts of realists attempting to mitigate anti-realist objections against epistemic optimism is commendable, it is a mistake to introduce an unnecessarily harsh epistemic pessimism – that diverges so much from the reasoning of the scientists themselves – in its stead.

## 6. Conclusion

The detectionist position was developed as a response to epistemic challenges such as the pessimistic meta-induction and underdetermination, and as such, it has been successful. The detectionist position regarding astronomical entities however, is still opaque and unclear. I call on detectionists to make their stance on these issues clear in order to provide a more comprehensive picture of their particular brand of scientific realism.

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