Dark Matter

Schedule & Abstracts

Philosophy of Dark Matter Workshop

Following up on the 2019 conference in Aachen on dark matter & modified gravity, and a special journal issue (in progress) on the same topic, the DFG-funded research unit Epistemology of the LHC and the Lichtenberg Group for History and Philosophy of Physics are organising a two-day workshop on the philosophy of dark matter. This workshop will take place on 29 and 30 March 2021. Philosophers, physicists, historians, sociologists and other interested scholars are invited to attend.

According to the standard model of cosmology, ΛCDM, the mass-energy budget of our universe includes roughly five times as much dark matter (DM) as the baryonic matter familiar to us from the standard model of particle physics. On the one hand, ΛCDM manages to connect an impressive range of phenomena at various scales, and has achieved a high degree of empirical confirmation. On the other hand, structure formation simulations involving dark matter run into a number of small scale challenges and fail to account for observed galactic correlations. Moreover, the exact nature of dark matter remains shrouded in mystery, despite particle physicists developing a cornucopia of ingenious particle dark matter models. In light of a persistent lack of non-gravitational detection of dark matter, the landscape of DM candidates spans 90 orders of magnitude in mass (!), ranging from ultralight bosons to primordial black holes. Some have gone as far as to suggest that it is a modification of the gravitational field rather than postulating a new form of matter that is required to account for all the data.

Despite the hunt for dark matter having been a large and important research programme in physics for decades now, the humanities have largely ignored it. However, dark matter, lying at the intersection of cosmology, astronomy and particle physics, provides a rich topic for philosophical exploration. This workshop will address some of the following research topics related to dark matter:

Descriptive questions:

- Which of the following factors have shaped and are shaping the DM research programme, and how: empirical data, theoretical virtues, idealisation, philosophical motivations and guiding principles, historical factors, sociological factors?
- How do constraints from cosmology, astronomy and particle physics interact?
- Which notions of direct and indirect observation/detection are relevant?
- Is the DM research programme in a crisis?
- Is the development of the DM research programme best understood via a Popperian, Kuhnian, Lakatosian, Laudanian or other analysis?
- What kind of underdetermination, if any, is there between dark matter and its modified gravity alternative?

Normative/epistemological/methodological questions:

- What is the epistemic status, robustness, and explanatory power of DM simulations and the various methods of DM detection/observation?
- What would it take to confirm that a new non-luminous particle discovered at the LHC is *the* cosmic DM particle?
- What would it take to abandon the DM research programme?
- Which criteria for theory choice could break the underdetermination, if any, between dark matter and modified gravity?
- Should dark matter be explored independently from dark energy?
- How should funding be distributed?
- What are good strategies for integrating dark matter, modified gravity and the humanities?

Semantic/metaphysical questions:

- What would it mean to currently be a scientific realist about dark matter?
- Do different communities mean the same thing when they talk about 'dark matter'?
- What makes one field a DM field and another field a modification of the gravitational field? Are dark matter & modified gravity mutually incompatible?

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March 23, 2021

	Monday 29 March	Tuesday 30 March
15:00	Opening **Antoniou:** Reliability, Informativeness and Sensitivity in dark matter observation	
16:00	Break **Martens** (realism) **De Baerdemaeker** (exploration) **Allzén** (confirmation)	**Meskhidze:** (What) Do we learn from code comparisons? A case study of implementations of self-interacting DM
17:00	Break	Break Panel session: **De Baerdemaeker, Jacquart, Smeenk & Sus**
18:00	**Vanderburgh:** Multi-Messenger Metaphysics: Evidence and Inference in Astrophysics and Cosmology	

Daylight savings will have just started in Germany, so all times are CEST.

Philosophy of Dark Matter

Notice that daylight savings will have just started in Germany (CET → CEST), so all times below are in CEST.

Besides four standard research presentation, the schedule contains one lightning round and one panel session. The lightning round consists of three brief talks, presenting the outline of planned projects on the philosophy of dark matter, like trailers of a movie. After each of these mini-talks there is some time for questions and suggestions how these projects could be best developed. During the panel session, the four panel members will reflect upon the workshop presentations and discuss other topics within the philosophy of dark matter, after which the audience gets the opportunity to join the discussion and direct questions at the panel. During the breaks it's possible to chat informally with other participants in the coffee room.

Monday 29 March

15:15–15:30 Opening

Chair: Niels Martens

15:30–16:30 **Reliability, Informativeness and Sensitivity in dark matter observation**
Antonis Antoniou

16:30–16:45 *Break*

Chair: Dennis Lehmkuhl

16:45–17:45 Lightning round

- 16:45–17:05: **Dark Matter Realism**, Niels Martens
- 17:05–17:25: **Exploratory Observations with Stellar Streams**, Siska de Baerdemaeker
- 17:25–17:45: **Dark Matter, Evidence, and Theory Confirmation**, Simon Allzén

17:45–18:00 *Break*

18:00–19:00 **Multi-Messenger Metaphysics: Evidence and Inference in Astrophysics and Cosmology**
William L. Vanderburgh

Tuesday 30 March

Chair: Michael Krämer

16:15–17:15 **(What) Do we learn from code comparisons? A case study of implementations of self-interacting dark matter**
Helen Meskhidze

17:15–17:30 *Break*

Moderator: Niels Martens

17:30–19:00 **Panel: Philosophy of Dark Matter**
Siska de Baerdemaeker
Melissa Jacquart
Christopher Smeenk
Adán Sus

Booklet of Abstracts

Reliability, Informativeness and Sensitivity in dark matter observation

MON
29 MAR
15:30

Antonis Antoniou
University of Bristol (UK)

The physics of dark matter can be probed by employing five different methods of observation: (i) via its gravitational effects, (ii) via precision measurements of cosmological observables, (iii) via direct searches, (iv) via indirect searches, and (v) via collider experiments. A natural question that arises is whether any of these methods is epistemically superior than the rest. The central aim of this paper is to answer this question by developing a way of evaluating the epistemic power of each method, based on the criteria of Reliability, Informativeness and Sensitivity. The main conclusion is that although these virtues are useful tools for evaluating the robustness of each method, the overall epistemic power of a possible observation of dark matter does not depend on the method per se. Rather it is a matter of the confidence of scientists in the underlying physics and the performance of the experimental apparatus.

Dark Matter Realism

MON
29 MAR
16:45

Niels Martens
RWTH Aachen University & University of Bonn (Germany)

According to the standard model of cosmology, ΛCDM, the mass-energy budget of the current stage of the universe is not dominated by the luminous matter that we are familiar with, but instead by dark matter (and dark energy). It is thus tempting to adopt scientific realism about dark matter. However, there is barely any constraint on the myriad of possible properties of this entity—it is not even certain that it is a form of matter. In light of this underdetermination I advocate caution: we should not (yet) be dark matter realists. The type of anti-realism I have in mind is different from that of Hacking (1989), in that it is semantic rather than epistemological. It also differs from the semantic anti-realism of logical empiricism, in that it is naturalistic, such that it may only be temporary and does not automatically apply to all other unobservables (or even just to all other astronomical unobservables, as with Hacking's anti-realism). The argument is illustrated by using as analogy the much longer history of the concept of a gene, as the current state of the concept of dark matter resembles in some relevant ways that of the early concept of genes.

Exploratory observations with stellar streams

MON
29 MAR
17:05

Siska de Baerdemaeker
Stockholm University (Sweden)

Recently, scientists have turned to stellar streams to trace out the substructure in the Milky Way dark matter halo (Bonaca et al 2019). I submit these observations constitute an example of exploratory observations in astrophysics, and I investigate how the use of eliminative reasoning enables this exploratory role.

Dark Matter, Evidence, and Theory Confirmation

MON
29 MAR
17:25

Simon Allzén
Stockholm University (Sweden)
Based on joint work with Jaco de Swart (University of Amsterdam)

The history of the dark matter problem knows an often-repeated narrative: the idea of unseen mass was introduced in the early 1930s but it was not until enough evidence had accumulated in the 1970s that scientists started to be convinced that the hypothesis must be correct. This textbook history of dark matter offers an interesting case study of how scientific theories are accepted. In particular, it fits perfectly in the most preferred way of reconstructing and justifying the acceptance of scientific theories: Bayesian Confirmation Theory. According to this theory, the credence, or subjective probabilistic degree of belief, in a hypothesis should change in response to new evidence. If evidence supporting the hypothesis keeps on increasing, your credence in the hypothesis is continually updated. Hence, the history of dark matter seems to validate a Bayesian way of understanding theory confirmation. Although the case study is interesting, the historical narrative on which it is based is fundamentally flawed.

In the current paper we follow the history of dark matter as discussed by de Swart (2017, 2020) to argue that dark matter's historical development actually forms a notable challenge to both Bayesian Confirmation Theory in particular, and to confirmation theories in general. Two parts of the historical development are key to these challenges: (1) the observations that came to function as salient evidence for dark matter in the early 1970s already existed independently in a different context; (2) the introduction of the dark matter hypothesis did not solely depend on empirical evidence. We argue that, if we take these developments seriously, we should reassess the notion of 'evidence' and its role in confirmation theories.

In particular, the history of dark matter shows that at least three aspects of 'evidence' should be made sense of in a theory of confirmation: (i) how certain observations become evidence without any change in the empirical content of the observations; (ii) how different subgroups can disagree on whether a phenomenon counts as evidence, and; (iii) how evidence can relate to a hypothesis without having a logical or probabilistic connection to the hypothesis.

Multi-Messenger Metaphysics: Evidence and Inference in Astrophysics and Cosmology

MON
29 MAR
18:00

William L. Vanderburgh
California State University, San Bernardino (USA)

An empirical methodology employed in multi-messenger astronomy can be extended to the task of justifying some of the metaphysical commitments and implications of cosmological and astrophysical theories—including, for example, the existence of dark matter. The "multi-messenger" methodology involves constructing several independent lines of evidence that together are mutually reinforcing and which thereby provide strong empirical support. Although the method shares features with what is called "multiple determination", it also includes additional consideration that make it more powerful. The paper shows that the multi-messenger methodology has its roots in Newton's empirical ideal of Reasoning from Phenomena; it argues that this methodology provides convincing evidence for the approximate truth of our best cosmological and astrophysical theories, including their metaphysical commitments and implications.

(What) Do we learn from code comparisons? A case study of implementations of self-interacting dark matter

TUE
30 MAR
16:15

Helen Meskhidze
University of California Irvine (USA)

Simulations have played a pivotal role in hypothesizing, investigating, and evaluating theories of dark matter. However, the reliability of these simulations is controversial. Some have argued that the fuzzy modularity and opacity of complex simulations leads to holism which undercuts our ability to develop analytic understanding (Lenhard and Winsberg, 2010; Lenhard 2019). Others have found traditional techniques of assessing their reliability lacking and have proposed alternatives (Gueguen 2020). Here, we turn to the context of cold dark matter (CDM) and the issues it faces on small scales to investigate the use of another traditional technique— code comparison. We investigate the implementation of self-interacting dark matter (SIDM), a proposal meant to resolve the issues CDM faces on small scale issues, in two simulation codes. Our project has the dual goals of analyzing the SIDM implementation in each code and studying the utility of a code comparison in increasing our confidence in the simulations. We find that when we isolate the effects of incorporating SIDM and change various SIDM parameters, there is broad agreement between the two simulation codes. We argue that it is the lack of a detailed prescription for a code comparison, not the fuzzy modularity and opacity of the simulations themselves, that hinders the potential utility of a code comparison and poses the biggest barrier to analytic understanding.
