# Inferring to the Presence of Matter

John D. Norton
February 6, 2018

In the cases of dark energy in cosmology and dark matter in galactic astrophysics, the same problem is posed. Are adequate conditions in place for us to infer to the presence of matter?

In neither case is there an automatic answer. In the case of dark energy, the observational evidence is fully accommodated by adding a cosmic $\Lambda$ term to Einstein's gravitational field equations. This term could equally be thought of as a matter term, contributing to the stress-energy tensor, or a geometric term, indicating modifications to geometry that arise even when no matter is present. In the case of dark matter, the alternative MOND theory seeks to accommodate the observations that support dark matter without any inference to a new form of matter, but from modifications to Newton's inverse square law of gravitational attraction.

More simply, we may just decide that the conditions for a matter inference are not in place and we remain agnostic as to the presence of dark matter and dark energy as forms of matter.

## 1. What Does it Take?

The question to ask is this: What does it take for observations to authorize an inference to the presence of a form of matter?

My sense is that this question has not been adequately answered. I do not have an answer here. Rather I am collecting ideas that might bring us a little closer to a good answer.

## 2. Examples Elsewhere

If there is a definite pattern to be found, we will be helped towards it by identifying more cases of matter inferences. Here is a short list.

*Inferences to new planets in the solar system.*

Neptune was discovered after the presence of a new planet was offered as an explanation of perturbations in the orbit of Uranus. Similar perturbations in the orbit of Mercury led to the postulation of the planet Vulcan. However it was not present optically and the hypothesis abandoned.

*Exoplanets*

Planets surrounding distant starts are inferred by several means.

The original method identified periodic shifts in the frequency of light from a star. Those shifts, it was inferred, were due to perturbing motions in the star resulting from the gravitational attraction of an orbiting planet.

In another method, the planet passes in front of the star, leading to a slight diminution in the star's brightness.

*Pathogens*

AIDS was initially investigated as a syndrome. A material cause was eventually isolated in the form of the HIV virus. More generally, the rules for identifying a microbial cause of some ailment are codified as Koch's Postulates:

1. The microorganism must be found in abundance in all organisms suffering from the disease, but should not be found in healthy organisms.
2. The microorganism must be isolated from a diseased organism and grown in pure culture.
3. The cultured microorganism should cause disease when introduced into a healthy organism.
4. The microorganism must be reisolated from the inoculated, diseased experimental host and identified as being identical to the original specific causative agent.

(from Wikipedia)

*Materiality of the field*

The examples so far are of inferences to ordinary forms of matter. At the beginning of the 20th century, electrodynamicists were prepared to ascribe materiality to field, such as the electromagnetic field. The key result was that conservation of energy and momentum requires that the field carry energy and momentum. This, in association with Einstein's $E=mc^2$, allows an inference to these fields being just another form of matter.

## 3. Independent Means of Identification

A common theme in these examples is that the inference to matter is only made after the matter has been identified by independent means.

The planet Neptune was identified by both its gravitational effect on Uranus and its visibility in a telescope. The second failed for Vulcan, which was abandoned.

Exoplanets can be identified by their gravitational effects on their star; or by their occultation of the light from the star. (Here however I don't know if the same exoplanet is detected by both means.)

Pathogens are identified by the correlation between the transmission of the clinically observed symptoms and the transmission of the microscopically observed microbe.

## 4. What is Matter?

This question tends not to be addressed directly. However its bearing is decisive.

The most direct answer is that matter is whatever our best theories of matter say it is. In seeking to identify dark matter as quantum WIMP particles, we are presuming that the matter in dark matter must conform with quantum theories of matter. In the case of dark matter, that may be reasonable. In the case of dark energy, whose properties are more exotic, is this the right characterization?

What other characterizations are possible? Is it adequate merely to identify matter with anything that has a gravitational effect?

## 5. Substance

A standard characterization of substance is that it is something that can exist independently. Establishing this independence is not so straightforward. One course is to check whether the candidate substance can vary in its distribution from other things. Non-uniform dark matter distributions have been identified, most notably by gravitational lensing. This suggests a form of independence. Proponents of MOND, however, have pointed out a "mass discrepancy-acceleration relation." It suggests that dark matter, if present, is not independently distributed in relation to other matter in galaxies.

## 6. Benchmarking

It is easy to think of an inference to matter as an all or nothing issue. Either we can infer to it or we cannot. However, in cases of uncertainty, the better model is that different circumstances admit different strengths of inference. How can we calibrate the strengths?

A strategy I find appealing is "benchmarking." That is, we compare different matter inferences as to their strength. My initial ranking is:

Planets, exoplanets, pathogens

stronger than

Dark matter

stronger than

Dark energy

The project is to make explicit what ground these judgments and to find more instances include in the comparisons.

Here I am not tempted by a Bayesian analysis. All it would do is to obscure the essential argumentation needed behind a fog of probabilities and give us an illusion of precision.