Introduction to the Epistemology of Science Seminar

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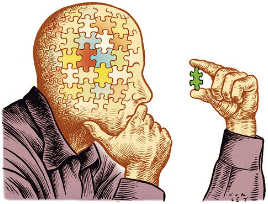
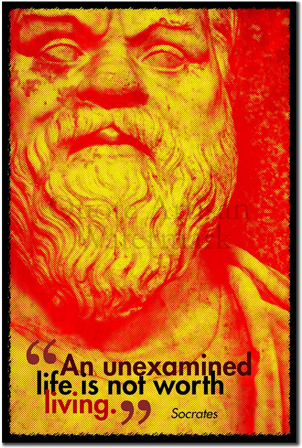
Science and Epistemology of Science



Christophe Vorlet:
https://vorlet.com//color-illustrations/

- What is science?
- Epistemology of science: study of the knowledge produced by science.

Knowing the World: First Step



- Socrates/Plato: dialectical discussion as a first step towards objective knowledge: grounded in the universal agreement between discussants.
- Socratic dialogues aims at reaching a consensus in the discussion when trying to answer to a particular question.
- Intersubjectivity as a necessary condition for objective knowledge.
- Is intersubjectivity enough to discover truths about the natural world? Probably not... We also have to examine closely the natural world!

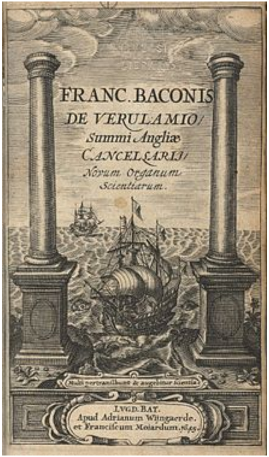
Knowing the World: Second Step

- Aristotle: empirical observations as a second step towards objective knowledge: grounded in the natural world.
- Induction from series of observations to general principles. (Not scientific, but essential to scientific knowledge).
- Deduction from the general principles to expected observations. (Scientific reasoning).
- Not the modern scientific method yet: observations and no experiments, induction is intuitive rather than scientific, and no mathematical method.

Knowing the World: Third Step

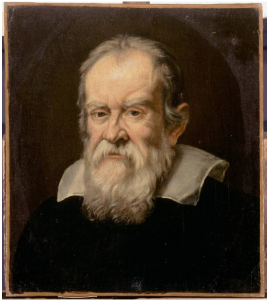
Experimentations and more rational ways to get at the first principles, by experimentations.

Francis Bacon (1561-1626)



the best demonstration by far is experience, if it go not beyond the actual experiment. For if it be transferred to other cases which are deemed similar, unless such transfer be made by a just and orderly process, it is a fallacious thing. (Bacon, *Novum Organum*, Book 1, Aphorism 70)

Knowing the World: Fourth Step



Galileo Galilei (1544-1562)

- Introduction of quantitative methods and mathematics.
- The world seems to be adequately described by the mathematics.
- It allows numerical predictions that can be calculated and compared with numerical observations.
- Move from a science of causes, to a sciences of effects (remaining silent about the causes of those effects)—influence of Galileo Galilei.

The Scientific Methodology in Brief

- Formulating theories with empirical consequences that may be checked.
- Two sides of scientific inquiry: a priori formulating of hypothesis, arguments with various conceptual tools.
- Assessment/confirmation/testing of theories is regarded as essentially connected to empirical procedures.
- However, in this seminar we will look into various proposals for non-empirical testing.

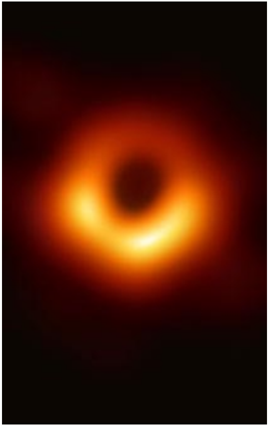
How Essential is the Empirical Component of the Scientific Method?

- What does it mean? Does it even make sense? Isn't it an unacceptable departure from the scientific method?
- We will look at three candidates for non-empirical knowledge:
  1) theory assessment in the framework of string theory;
  2) analogue simulations and
  3) computer simulations.

Semester Agenda

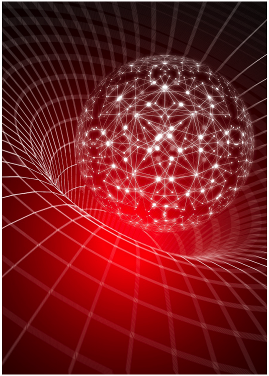
- 1. String theory and the quest for quantum gravity.
  (Seminars 2 and 3)
- 2. Analogue experiments/simulations.
  (Seminars 4, 5 and 6)
- 3. Computer simulations.
  (Seminars 7-11)
- 4. Cosmology.
  (Seminars 12-13)

Why General Relativity and Quantum Field Theory are not Enough



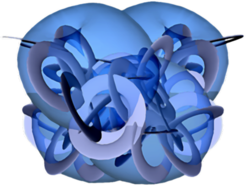
The paradigm of confirmed physics cannot fully explain phenomena which are both gravitational and quantum. For instance black holes, the earliest instants of the universe or the nature of space and time.

Quantum Gravity



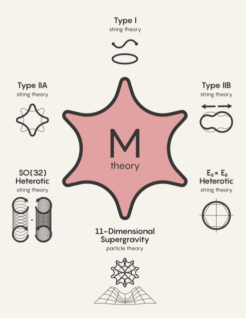
- We need a novel quantum theory of gravity in order to account for those phenomena.
- The two most popular approaches (in number of physicists involved) are: string theory and loop quantum gravity.

String Theory



- According to string theory the world is fundamentally made of 10, 11 or... 2 dimensions.
- No particles: one-dimensional entities called strings as they oscillate.

String Theory

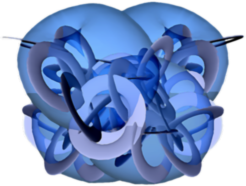


- It's a research program with no comprehensive and sorted out ontology. The best things we have, perturbative superstring theories, rely on a ten-dimensional structure.
- Conjecture of a more fundamental non-perturbative M-theory describing a world made of 11 dimensions.

Epistemology of Science in Intermediary Times

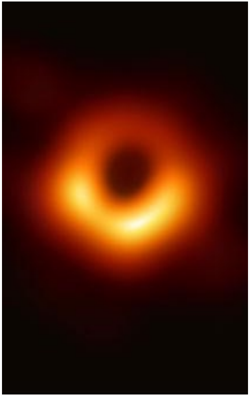
Similarly, to the extent there are reasons to assume that string theory or the multiverse have a high chance of being viable, that constitutes an important element of knowledge about the universe even in the absence of conclusive empirical confirmation of those theories. [...] It may still make sense to ignore intermediate epistemic states between ignorance and conclusive knowledge in contexts where they last only for a brief period of time before the case is settled based on conclusive empirical evidence. In contemporary fundamental physics the typical time scale for that intermediate state has grown beyond the length of a scientific career. (Richard Dawid, 2019, p.103, week 2)

How to Confirm String Theory?



- If theories of quantum gravity are doomed to remain beyond empirical testing for a while, can we confirm them on a priori grounds?
- Confirmation and confirmation: ambiguity between conclusive confirmation and partial confirmation.
- Could we partially or conclusively confirm a scientific theory such as string theory or another view on quantum gravity without empirical evidence? (Weeks 2 and 3).

Black Holes and Hawking Radiation



- Black holes are conjectured to emit Hawking radiation.
- Relies on a specific framework: Quantum field theory in curved spacetime. No influence of matter on the spacetime geometry. Hybrid framework, hard to trust.
- Unless we find extremely small black holes (emitting stronger radiations), we will never be able to directly observe those radiations.
- It has been suggested that one may probe indirectly the properties of a black hole by examining the properties of analogous physical systems.
- If this is correct, one might hope to find Hawking radiation, or an equivalent of it, in other physical systems.

From Rainbows to Black Holes 1/2

[Universality] refers to the existence of patterns of behavior by physical systems that recur and repeat despite the fact that in some sense the situations in which these patterns recur and repeat are different. Rainbows, for example, always exhibit the same pattern of spacings and intensities of their bows despite the fact that the rain showers are different on each occasion. They are different because the shapes of the drops, and their sizes can vary quite widely due to differences in temperature, wind direction, etc. (Batterman, 2019, 26, week 4)

From Rainbows to Black Holes 2/2

- This stability here is not cross-temporal stability.
- Independence of a macro-system with respect to the details of its micro-constituants.
- Various rainbows obey some rules that seem autonomous with respect to the micro-constituants.
- Could we find a system like that for black holes, more accessible to testing?

Black Holes and Dumb Holes

Illustration by David Simonds, economist.com/science-and-technology/2009/06/18/dumb-insolence

- Sound waves in fluids encounter a horizon (compare: light waves in spacetime encounter a horizon).
- Idea that black holes and the dumb holes share coarse-grained properties (such as Hawking radiation) which are insensitive to their more fine-grained properties.
- More generally, this idea relies on the principle that a target system (say a black hole) can be partially and fruitfully modeled by another physical system, the source system (say a dumb hole).

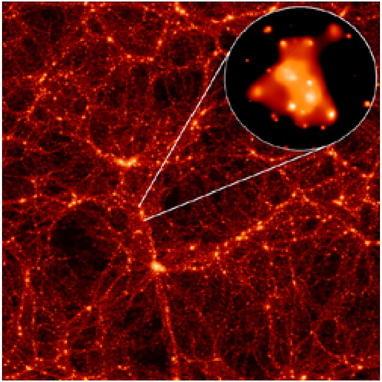
Analogue Experiments

- One way to explain why the target system is accurately described by the source system is that both the target system and the source system belong to the same universal class.
- Universality to be related to multiple realizability in the philosophy of mind, or with the idea that various tokens participate of the same type in metaphysics.
- Prompts various questions: is the natural world like this? And can we know with certainty that a black hole and a dumb hole belong to the same type of phenomena, ensuring that no micro-physics will kick in, breaking the analogy? (Weeks 5 and 6)

Computer Simulations are Everywhere in Science

Computer simulation was pioneered as a scientific tool in meteorology and nuclear physics in the period directly following World War II, and since then has become indispensible in a growing number of disciplines. The list of sciences that make extensive use of computer simulation has grown to include astrophysics, materials science, engineering, fluid mechanics, climate science, evolutionary biology, ecology, economics, decision theory, sociology, and many others. There are even a few disciplines, such as chaos theory and complexity theory, whose very existence has emerged alongside the development of the computational models they study. Until relatively recently, however, philosophers of science have paid little attention. (Winsberg, 2009, 835, week 7)

Computer Simulations



(Credit: Virgo consortium; Reference: Jenkins et al. 1998)

What's a computer simulation?
Does it differ from experiments and if so... how?

What's a Computer Simulation?

- "We can think of computer simulation as a comprehensive method for studying systems that are best modeled with analytically unsolvable equations." (Winsberg, 2009, 836, week 7)
- Analytically unsolvable equations are equations that we cannot solve exactly by manipulating mathematical symbols. Still, we can bypass this difficulty in part by very complicated approximations that require substantive calculation time.
- If we want precise results, we need computers.

Distinctive Features of Computer Simulations?

- "[The] knowledge produced by computer simulations is the result of inferences that are downward, motley, and autonomous." (Winsberg, 2009, 837, week 7).
- Downward: from a particular theory to particular features of phenomena. (Not from observations/experiments to a theory.)
- Motley: relies on various sources. "These include theory, but also physical insight, extensive approximations, idealizations, outright fictions, auxiliary information, and the blood, sweat, and tears of much trial and error." (Winsberg, 2009, 837, week 7).
- Autonomous: the results of computer simulation cannot be completely sanctioned on external ground, by looking at the world.

Are Computer Simulations Experiments of Inferences?

- Are computer simulations experiments or inferences? (*Weeks 8-11* with texts from Parker 2009, Beisbart 2018 and Boge 2019.)
- How can we learn something about the world by running an algorithm on a computer?

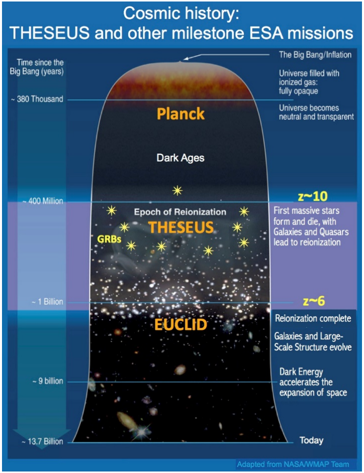
Guest Speaker: Vincent Lam

Vincent Lam (prof. at Universität Bern) will present his research on simulations and climate sciences (week 9).

Cosmology

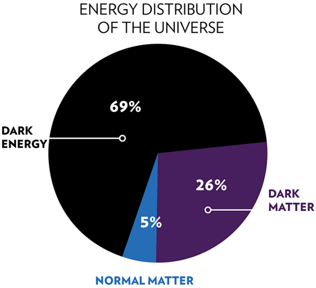
- The last two weeks will focus on cosmology as a difficult case study for epistemology of science.
- "The standard model of cosmology (SMC) is based on bold extrapolations of theories that have been well tested by Earth-bound experiments and astronomical observations." (Smeenk 2017, 212, week 13)

The Standard Model of Cosmology 1/2



The interpretation of cosmological data depends, to varying degrees, on a background cosmological model, and hence assumes the validity of extrapolating general relativity to length scales roughly 14 orders of magnitude greater than those where the theory is subject to high precision tests. (Smeenk 2017, 212, week 13)

The Standard Model of Cosmology 1/2



The SMC describes the contents of the universe and their evolution based on the Standard Model of particle physics, supplemented with two distinctive types of matter–dark matter and dark energy–that have so far only been detected due to their large-scale gravitational effects. Cosmological observations performed over the last few decades substantiate the enormous extrapolations and novel assumptions of the SMC. (Smeenk 2017, 212, week 13)

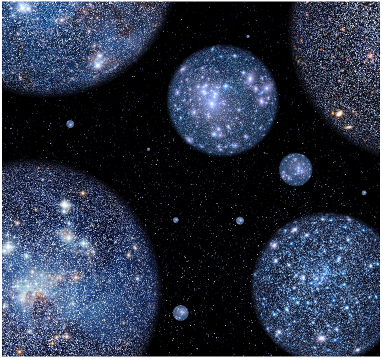
Guest Speaker: Marie Gueguen

Marie Gueguen (postdoc at the University of Pittsburg) will present her research on simulations and cosmology (week 12).

Inflation

- Inflation is a theory supposed to complement the hot big bang theory.
- The view is that an extremely fast expansion of space happened after the big bang, explaining for instance why seemingly causally disconnected regions of spacetime may share the same physical properties.
- Inflation seems highly more speculative than the rest of the cosmological model and we will discuss to what extent we may be confident in its truth.

Multiverse Inflation



Victor De Schwanberg / Science Photo Library via Getty Images

The most recent inflation theory—eternal inflation—seems to "imply that all possible observations are realized somewhere in a vast multiverse" (Smeenk, 2017, 206, week 13).

Eternal Inflation

- As with Lewis possible worlds in metaphysics, with the landscape in string theory or with the many-worlds approach to quantum physics.
- Can we really test the existence of a multiverse?

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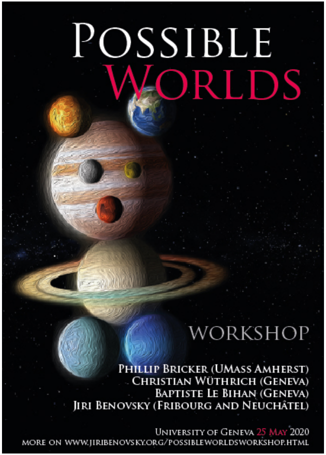

Possible Worlds Workshop
in Geneva on May 25 2020
http://www.jiribenovsky.org/possibleworldsworkshop.html

Eternal Inflation

- The text we will discuss (Smeenk 2017) offers negative answers.
- First, inflation cannot be trusted.
- Second, eternal inflation leads to specific issues.
- Do we really understand the cosmos, namely the universe as a whole?