

On Epistemology of the Celestial Realm

Aditya Singh

1.1 Introduction

Astronomy is the branch of science concerned with the study of matter in outer space. The methods of constructing knowledge in astronomy are unlike those which are used in other fields of scientific inquiry. This is particularly so because astronomers deal with processes which, many-a-time, cannot be either explored experimentally or observed given present day technology. In this paper, Rationalistic tools, like mathematics and logic, and Empirical tools, like sense observations and quantitative measurements, are discussed as complementary approaches for constructing astronomical knowledge.

From the discussion that follows, it will be shown that for producing a sound and reliable theory in astronomy, one must follow a *mathematico-deductive* pattern of starting with a rationalistic approach and developing a general relation describing a phenomenon. This relation should then be confirmed empirically through *specific* observed data. On the other hand, inductively forming a generalization by directly using empirical data in a conventional *hypothetico-deductive* model faces a high risk of resulting in inaccurate astronomical knowledge.

1.2 Scope of Thesis

The argument presented shall work on the assumption that nature is uniform, and the analytic rules of logic and mathematics relate to the physical world as shown by the equations and theorems. *Uniformity of Nature* implies that an event that occurs at one place and time will occur again at any other place and time if the relevant conditions are the same. This assumption is required for the working of any law.

On Epistemology of the Celestial Realm

Also, for the purposes of discussion, empiricism will be discussed in the context of *Direct Realism*, where sensory perceptions are a reliable source of information of the external world. This assumption is necessitated for a pragmatic analysis of the scientific method, as sensory observations are considered essential components for constructing knowledge in the sciences.

Also, as Immanuel Kant pointed out, ‘all our knowledge *begins* with experience, but it does not follow that all our knowledge *arises* out of experience’. The difference between the two should be understood, since an empirical observation is required to kick-start any search for knowledge, even in the case of astronomy. However, the empiricists’ point discussed in this paper is the one that claims that sense datum can be *used* to construct knowledge vis-à-vis the scientific method in astronomy.

2.1 The Scientific Method

The Scientific Method is the process by which scientists construct an accurate representation of the world using a set of standard techniques, which help minimize the influence of biased beliefs on the development of a theory. Scientists rely on two distinct types of analysis for creating theories and explanations in any field: *Inductive Reasoning* and *Deductive Reasoning*. While inductive reasoning involves extrapolation from a set of finite observations, deductive reasoning is based on a system of syllogistic logical arguments, or on *a priori* statements, like those in mathematical conjectures.

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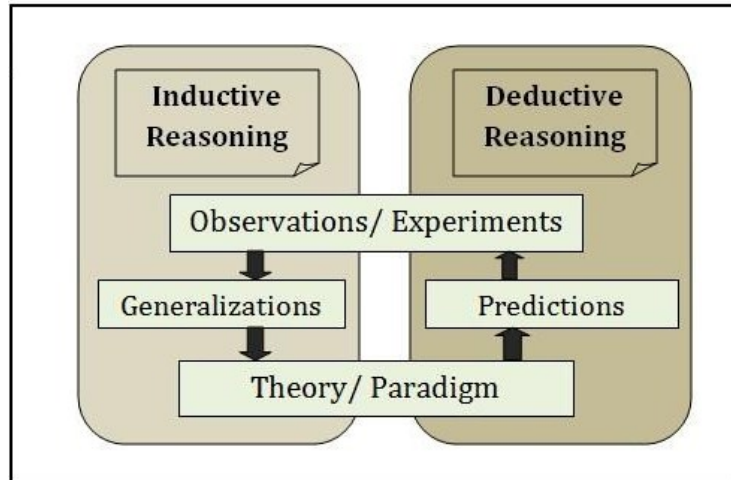


Figure 1: Diagrammatic flow of Inductive and Deductive Reasoning

The conventional Scientific Method makes use of both inductive and deductive processes to construct theories. It begins with certain observations of nature, on the basis of which scientists creatively and inductively suggest a hypothesis as an explanation. Working with such a hypothesis, experiments are conducted and logical tests are formulated which would result in certain observations, under the given conditions, if the suggested hypothesis is true. Through such a trial-and-error process, a theory which fits the observational data and has a predictive capability is worked out.

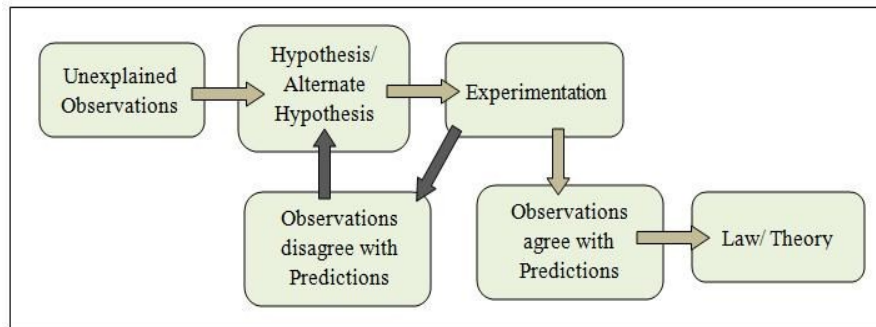


Figure 2: The Conventional Scientific Method

On Epistemology of the Celestial Realm

2.2 Breakdown of Scientific Method in Astronomy

When the conventional scientific method is applied to astronomy, it is noticed that it does not aid one in constructing reliable theories mainly due to two reasons. Firstly, outer space observations usually consist of rare or one-time phenomena, which occur once in a few million years. Due to this, an inductive pattern is hard to find since the data sample is limited to just a few observations. Secondly, one cannot repeat the processes in a laboratory and conduct tests using the same conditions as outer space. In many cases, it is not even possible to detect or observe a particular phenomenon directly. For instance, the human race is not technologically advanced enough yet to explore distances billions of light years away, being a *Type-Zero* civilization at present harnessing only a portion of the energy available on our planet (Kaku 2008, 34-53). Since these two major steps of ‘experimentation’ and ‘observation’ that lend certainty to the scientific process cannot be carried out effectively, the inductive element of this method – when applied to astronomy – runs a high risk of being inaccurate.

One of the fundamental aspects of astronomy is that there are a number of processes that are unobservable. For example, a *Black Hole* is a celestial body whose gravitational force is so high that no electromagnetic signal can escape its pull (Wheeler 1967). Since these signals received from outer space objects are the empirical data on which an inductive model is built, scientists have no way of constructing knowledge on a strictly observational basis when dealing with phenomena like black holes, superstrings, quasars, and of the sort.

The only way such objects are detected is through some indirect evidence of their existence. These could be high powered X-ray generation from a given point in space, distortions in gravitational fields, or even a visible star orbiting an ‘unseen’ companion. But at the same time, it should be noted that there are any number of objects that could be responsible for X-ray generation and gravitational distortion (which may not necessarily be the objects under study). Also, the ‘unseen’ star could simply be a star that is too faint to be seen.

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One cannot be certain of such indirect evidence as proof for the existence of a particular phenomenon.

Experimentation under varying conditions is another important step in the scientific method, since it helps to derive a relation of what ‘causes’ lead to a particular ‘effect’. It becomes highly difficult to conduct laboratory tests for laws concerning celestial bodies as the conditions required for the processes are too extreme to be simulated. For example, one cannot recreate the fusion reactions taking place inside the Sun’s core to understand the mechanism of radiation in stars, or construct multi-dimensional parallel universes. Astronomy is not like other laboratory sciences where the experimentalist is able to vary and control the environment or the conditions under investigation. The ‘experiment’ is a process going on out in space, and the astronomer only collects data from the ‘results’ of that on-going experiment. Apart from this, celestial phenomena generally take millions of years to develop and occur. When dealing with such a huge time-span, it is not possible to take a number of observations from the different ‘experiments’, or processes going on in space, and then find a common pattern in the information received.

Therefore, it is necessary to provide an extension to the laboratory laws, or perhaps invoke new laws through non-empirical means to understand and describe such rarely observed and difficult to simulate phenomena occurring in outer space.

3.1 Deduction as a Possible Solution

Although it is a powerful and essential tool in science, inductive reasoning must be treated with skepticism since it is based on limited sample data, and its predictive capacity is restricted to the repetitive nature of the phenomenon which governs its construction. If one extends a given case to the general by means of induction, he assumes – in the very act itself – that induction is actually a workable and correct process. It is evident that without forming a vicious circle and begging the question, a generalization from a specific cannot

On Epistemology of the Celestial Realm

be demonstrated by this process (Russell 1997). This is a major logical problem with justification in inductive reasoning. Induction speaks more of probability in its conclusions than deterministic certainty.

Astronomy is, like any other science, a law-governed nomological study (Kragh 2001, 157-69). Since empirical means can be relied upon only to a limited extent for cosmological occurrences, it becomes necessary to develop an entirely deductive theory of astronomical knowledge, which more or less removes the element of inadequate experiential ability.

Unlike induction, deductive reasoning is perfectly reliable if one has used the correct premises and logical structure. If the foundational statements on which deductive knowledge stands upon consists of self-evident or transcendental truths, the derived conclusions will also be axiomatic in nature. The tools of mathematical theorems and logic can thus aid us in compiling a consistent scientific theory for astronomy (Douglas 1945, 73-88).

History provides evidence to support this line of reasoning. Johannes Kepler, who solved the problem of planetary motion, initially believed (based on his observations) that the circle – being the perfect curve – was the only path a planet could follow. He later acknowledged that his mathematical results ‘forced’ him to conclude that the planets should be following an elliptical path with the Sun as one of the foci (Tarnas 1993).

3.2 Deductive Nature of Mathematics

Mathematical knowledge seems to have a kind of certainty that exceeds other forms of knowledge. Since the structure of mathematics is based entirely on a system of analytic *a priori* statements, it is noticed that all demonstrations in this field are deductive in nature. This rationalistic consequence of mathematics has immense implications on the theory of knowledge. For one, we realize that mathematical knowledge requires premises which are not based on sense datum. Any general proposition in this subject goes beyond the limits of knowledge

LYCEUM

obtained empirically, which is entirely limited to what is individual (Slater ed. 1988).

If the steps carried out in formulating a conclusion are mathematically correct, then the claims of the knowledge produced cannot be disproved. This knowledge is then 'static' in nature, and can be fully relied on as being true.

3.3 Mathematical Construction of Knowledge in Astronomy

The most powerful method of advancement in astronomy is to employ the resources of pure mathematics in attempts to generalize the mathematical formalism that forms the existing basis of theoretical astronomy. These new features should then be interpreted in terms of physical entities (Dirac 1973). The application of such a method would lead to the construction of reliable knowledge in astronomy. If a Euclidian triangle is found by measurement not to have angles totaling 180° , we do not say that we have met with an instance which invalidates the summation law of polygon angles. We always preserve the validity of a mathematical truth by adopting some other explanation for the occurrence. This is our procedure in every case in which a mathematical truth seems to be confuted. Thus, finding the mathematical principles governing celestial phenomena will grant our knowledge-system immense certainty. Once proven, these laws remain as static knowledge and allow us to make assured advances in astronomy.

Without mathematical models and physical equations – which are used as unifying and generalizing structures for data – astronomical science would cease to function, since all we would be left with is a bewildering assemblage of apparently unrelated observations that we would try to make sense of using an apparently unjustified common sense.

Moreover, such mathematically derived theories suggest the existence of other hitherto unsuspected natural phenomena, thus endowing scientific inquiry with a 'predictive capability' (Young 1983, 939-50). For example, from the gravitational behavior of the universe, it is logically estimated that

On Epistemology of the Celestial Realm

'*Dark Matter*' comprises about 25% of natural matter in the form of weakly interacting massive particles. *Dark Matter* is a hypothesized form of matter particle that does not reflect or emit electromagnetic radiation. These particles have not been detected in any form, and are only predicted to exist by extensions of our current knowledge about intergalactic gravitational effects. Such knowledge is created to explain structures and phenomena that are entirely outside the range of all direct human experiences. Through such rationalistic reasoning, it becomes possible to make assertions, not only about cases that we have been able to observe, but also about all actual or possible cases.

4.1 Extension of System for Knowledge Construction

If knowledge in astronomy is constructed through mathematics, an important implication follows in so much as we can not only formulate astronomical theories by working *within* the current mathematical framework, but can also extend our mathematical means to create additional tools for constructing theories *outside* the existing structure.

In constructing knowledge within the existing structure, a new theory is devised which is actually a mathematical extension of the previous theories. It involves tinkering with equations and working out new expressions which might help in explaining a certain phenomenon or process. For instance, accurate observations of Mercury's orbit revealed small differences between its predicted motion as per Newton's theory of gravity, and its actual motion. Einstein's general theory of relativity, which has its mathematical foundations in Newton's theory, predicted a slightly different motion, which was found to be matching with the actual path.

When constructing knowledge outside the existing system, the scope of the subject itself needs to be extended by formulation of new techniques that increase the application of mathematics in astronomy (Hawking 1998). When dealing with certain problems in physics, Isaac Newton realized that the mathematical knowledge existent at that time was inadequate for him to provide

LYCEUM

possible solutions. Thus, he developed ‘*Fluxions*’ for the application of his mathematical equations to *differentials* in nature. This laid foundations for modern-day *Calculus*. Such inventions of mathematical devices then help to extend knowledge in the astrophysical arena.

4.2 Validation of Rationally Constructed Knowledge

Since mathematically constructed knowledge is completely reliable when used with correct premises and suitable steps, it is possible that scientists would place undue trust in claims made on a deductive basis. Mathematical claims need to be carefully examined in order to check that the assumptions, or premises, are sound and the reasoning is valid. To validate the theories, it should be ensured that *specifically* predicted observed data fits well within the explanations of the theoretical framework. Thus, deductions tested under new observational programmes support the theories or cast doubt upon their validity. The observations that do not fit into the mathematical framework should be treated as indications that another theory or explanation is required for the given problem.

As an example in astrophysics, the *String Theory* enjoys consistency only in a *10-dimensional* universe. This hypothesis is a purely theoretical construct with no experimental evidence for support, and its inability to be tested or falsified by near-term experiments or astronomical observations prevents it to be accepted as ‘knowledge’ within the scientific community as of yet (Naeye, 2003, 39-44).

Testing the concepts empirically is a critical step in the construction of scientific knowledge, often having a profound influence on what is considered knowledge and what is disregarded as invalid supposition (Zycinski 1984, 137-48). By this ‘empirical testing’, I do not mean that we can entirely trust our observations (since that is the reason we resort to a *mathematico-deductive* model for constructing knowledge in astronomy). Rather, after the ratiocination of a conjecture in a model, we are better acquainted with the distortions that the

On Epistemology of the Celestial Realm

sense datum might have undergone before being received by us, and we can take these into account while testing our concepts and theories empirically; we do not take the observations at face value to construct a theory.

The evidence of the senses should agree with the truths of reason but it is not required for the acquisition of these truths. Repeated observations and experiments function solely as ‘tests’ of conjectures or, as Popper would have put it, attempted refutations. Irreconcilable failures of theoretical predictions to agree with empirical data leads to abandoning of the theory in search of another (Young 1983, 939-50). Faults, if any, *within* the existing *mathematico-deductive* structure are then investigated. If no such discrepancies are found, then new mathematical systems are explored, that is, the system is extended to create knowledge *outside* the existing structure. The full appreciation of this explanation makes the relation between theories and observations clear.

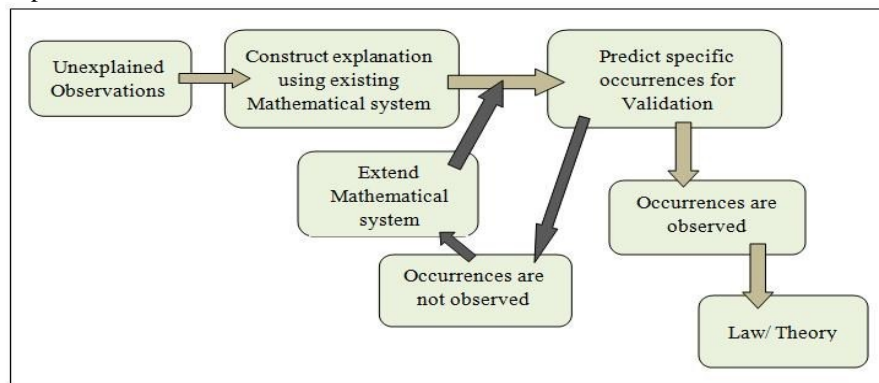


Figure 3: The modified Scientific Method for Astronomy

4.3 Epistemological Testing of Knowledge

In Platonic terms, ‘Knowledge’ is defined as a proposition that is a *justified true belief*. Since induction presupposes an inductive statement and relies on falsifiable empirical sample data (in astronomy) for the purpose of justification, it can be safely said that induction provides us with a true belief, rather than

LYCEUM

certain 'knowledge'. This true belief lacks firm grounds, and can therefore be disproved.

On the other hand, the *justification* for rationally constructed knowledge is provided through *specific* empirical observations predicted beforehand. The element of *truth* is evident since mathematical conjectures are *analytic a priori* statements, and hence, the knowledge thereby constructed is true by definition. It is, therefore, in the nature of mathematical knowledge that a theorem, formed purely on the basis of deductive reasoning using axiomatic truths, cannot be argued with. One realizes that knowledge can be better constructed using deductive means as it can be defined in much more precise terms than that which is created empirically and inductively in astronomy.

5.1 Conclusion

The relation between mathematics and astronomy is the utility of the former in the pursuit of the latter. Perhaps the reason we cannot predict anything happening near the singularity region of a black hole is because our present mathematical laws and equations cease to be applicable under the conditions prevalent in that area. This leaves us with no tool to construct our knowledge with.

Thus, it is abundantly clear that our very limited direct experience with the real physical world in no way qualifies us to pontificate upon nature in its entirety. We can comprehend more about outer space in an intuitive way using the theories that we conceive in the form of abstract mathematical structures, than those that purely rely on available empirical information.

5.2 The Pursuit of Knowledge -An After Note:

It is worth noting at this point that modern commentaries on the erroneous descriptions of Ptolemy's model of the universe reveal an unjustified contempt for a theory that was remarkably successful in accounting for the then known

On Epistemology of the Celestial Realm

phenomena of the celestial sphere (Roy and Clarke 2003). A theory - or knowledge in general - is something that is a creation of our minds; it has no independent physical existence of its own, but it helps us explain reality. Pragmatically speaking, Ptolemy's theory was correct and dependable. But when constructing theories in the sciences, we are searching for knowledge which is *correspondingly true*, that is, it corresponds to the *actual way the things are* in reality. That is the foremost reason why we must not be satisfied by merely constructing a *pragmatically true* theory which helps us make accurate predictions, or explain observed natural phenomena; we must endeavor to find the actual mechanism and phenomenon as it *is* happening, even if we cannot observe it.

Such a leap enables us to investigate that part of the universe that is beyond the range of our sensory perception. For such epistemological pursuits, we must make use of abstract mathematical formulations, for the 'world' which they are exploring is also, perhaps, as abstract as those numbers and equations.

Anglo-Chinese Junior College
Singapore

LYCEUM

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On Epistemology of the Celestial Realm

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