

# **ABDUCTION, IBE, AND THE DISCOVERY OF KEPLER'S ELLIPSE**

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## **1. Introduction**

Most accounts of abduction and inference to the best explanation (or IBE) in epistemology and philosophy of science proceed at the abstract level, and the proposed examples are usually relatively simple and well-defined. In this paper, I will examine what happens when they are applied to the more complex example, namely Kepler's discovery that the Martian orbit is ellipse. It turns out that at least in this example abduction and IBE lack resources for the historically accurate description of complex discovery process. On the other hand they may be useful for explaining why the discoverers thought that their new results are justified or worthy of further attention. In other words, abductive inference and IBE could provide historically sensitive models of justification.

But first some familiar distinctions. We should make a distinction between abduction and inference to the best explanation on the first hand, and between their roles as heuristic models of discovery and models of justification on the other. As usual, by abduction I mean the reasoning process from the evidence base and background knowledge to the hypothesis or explanans that explains the relevant evidence. IBE is a refinement of the abductive method in which the role of background knowledge is made more explicit by demanding that we should choose from the relevant store of hypotheses the one that best explains the evidence. The notion of best explanation is of course relative to the principles of ranking competing explanations.

Both versions of the basic idea may be used as heuristic models of discovery or models of justification. If they are used as heuristic models, we focus on their ampliative nature, on how they give heuristic guidelines to the search of explanations. The outputs of abduction or IBE may contain concepts or ideas which are not included in the description of the evidence. In the typical case, they are not just inductive generalizations of the evidence base, but may also contain conceptual novelties. Their difference is that whereas the output of abduction may contain new elements which transgress even the background knowledge, the store of competing explanations in the case of IBE is usually ordered according to the dimensions specified in the background knowledge.

Abduction and IBE could also be used as models of justification. The conclusion of abduction is providing reasons to believe abducted explanation to be true or acceptable by some other standard. Similarly, IBE provides reasons to accept the resulting explanation as true, since the result is the best one according to the ranking criteria. Note that this does not guarantee that the conclusions of these methods are in fact true. As many sceptical commentators have argued, the best explanation is not always the true explanation or even the likeliest explanation (van Fraassen 1989, Lipton 1991).

## **2. Abductive Account of Kepler's Discovery Process**

In this section, I will examine the prospects of abduction as a model of discovery. How could it function in the discovery of scientific hypotheses? How could it describe complex historical examples of prominent discovery processes? My discussion starts with the short overview of

Kepler's discovery process and Norwood Hanson's reconstruction of it in his *Patterns of Discovery* (1958).<sup>1</sup>

The starting point of Hanson's argument was criticism of the hypothetico-deductivist account of the logic of science. H-D accounts are restricted to "the logic of finished research reports" whereas the most interesting aspect of, for instance, Kepler's and Galileo's work is their innovative reasoning from evidence to hypotheses. According to Hanson, hypothesis formation should have an important role in the philosophy of science. To illustrate the importance of discovery he chose as his main example Johannes Kepler's research which is described in *Astronomia Nova* (1609). The book contains an extraordinary detailed description of the discovery process which led, among other innovations, to the results later named as Kepler's first and second law.

Originally, Kepler's desire was to use Tycho Brahe's observations to find new evidence for his archetypal theory of the universe which he presented in his first book *Mysterium Cosmographicum* (1596).<sup>2</sup> In 1600 he came to Prague where Tycho Brahe was appointed as an imperial astronomer. After Tycho Brahe's death in 1601, Kepler was nominated to be his successor, and his commission was to produce new planetary tables using Tycho's accurate observations. Now he concentrated on the task of construing the improved planetary model of Mars. However, the task turned out to be a difficult one, and it took Kepler four or five years (ca. 1600-1605) to complete the inquiry. As a result, he presented the ellipse-based model of Mars.

Kepler started by revising the previous models of Ptolemy, Copernicus and Tycho Brahe, and arrived to his first model of Mars, the so called vicarious hypothesis (I will refer to it as M[1]). By the vicarious hypothesis Kepler could calculate correct longitudinal positions for Mars but it was not as reliable with latitudes or distances. Moreover, Kepler thought that some of its elements were not physically realistic. The central element of M[1] were Ptolemy's equant point device. Non-uniform speed of the planet along its path could be described by this device, since the angular velocity of the planet around the equant point is uniform. Kepler's worry was that the equant point is not physically real point in the space. It is only a mathematical tool which does not have any causal role in the production of the planet's movement. Kepler's goal was to replace the abandoned Aristotelean physical theory of solid crystal spheres by the causal account of the forces which move the planets. The geometric description of the celestial movements was not enough.

So the inquiry continued. In the next phase Kepler developed a renewed model of the earth in which the earth also has an equant point (it is an important presupposition for the proper interpretation of observations), and created a physical account of the forces which move the planets (see Stephenson 1987, for details). Kepler tried to incorporate the principles of physical astronomy to his geometric calculations by the technique which was called the area method.

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<sup>1</sup> For a more through presentation of Kepler's background as well as his reasoning in *Astronomia Nova*, see Aiton (1969), Wilson (1968), (1972), Koyre (1973), Krafft (1991), Stephenson (1987), Kozhamthadam (1994). An english translation of *Astronomia Nova* is currently available as Kepler (1992). In the sequel, I shall use the shorthand AN for this book. There also are several philosophical interpretations of Kepler's work.

The important contemporary contributions to this discussion are Hanson (1958), Kleiner (1983), Lugg (1985), and Kozhamthadam (1994). There are also many earlier contributions, for instance, in the methodological writings of Mill, Whewell, and Peirce. See Wilson (1974).

<sup>2</sup> Kepler's own biographical account is given in Chapter 7 of AN, see Kepler (1992), pp. 183-7.

By taking these new elements into consideration, Kepler construed another model in which the equant point was replaced by the area principle and the epicycle theory (I will refer to it as M[2]). However, he was not able to achieve acceptable model of Mars from this modified model either, so that he finally started to doubt the assumption that the orbit is a circle or combination of circles. He tried to improve the situation with still another modified model, M[3], in which the circular orbit was replaced by the oval-shaped orbit. The final model M[4] with the ellipse came when even M[3] failed.

The reasons for the failure of both M[2] and M[3] were similar, namely the disagreement of the calculated predictions with the reliable observations. The calculated longitudes of Mars were not in accordance with the ones given by the M[1] (which agrees with Tycho's observations in the case of longitudes). Kepler checked the longitudes in the apsides, quadrants and octants, and noticed agreement in the apsides and quadrants but an eight minute discrepancy in the octants. Reflecting on the nature of this deviation, Kepler adopted the view that the orbit of Mars is oval (egg-shaped), since the oval curve approximates the circle in the quadrants and observed errors in the octants.<sup>3</sup> In the case of M[3], Kepler calculated longitudes using an auxiliary ellipse and assuming the area method. Now the calculations resulted in opposite errors when compared to the previous ones with M[2]. The errors were again about eight minutes or arc in the octants but their signs were reversed.

Ellipse was first a mathematical auxiliary which approximated the oval orbit. But later Kepler found out that observations as well as the conclusions of his physical theory could be saved only if the orbit is ellipse.

Every step in this process involved careful attempts to determine new versions of planetary models. Kepler was constantly driven into situations in which he have to weight different models and values of their parameters, and choose whether to abandon or revise them. In fact, his first two "laws" were byproducts of this type of reasoning. The discovery of elliptical orbit and the area method was, then, a kind of unintentional byresult of several lines of arguments.

For summary, here is a rough list of Kepler's models:

M[1]: "vicarious hypothesis", circular orbits with Ptolemy's equant point device

M[2]: the renewed theory of the Earth, theory of forces, distance law, area method, circular orbit, epicyclic movement

M[3] : oval-shaped orbit, auxiliary ellipse, theory of forces, area method, irregular epicyclic movement

M[4]: elliptical orbit, theory of forces, area method

Now we finally come back to the Norwood Hanson's reconstruction of Kepler's discovery process. In order to study "logic of discovery" Hanson adopted Peircean *abductive or retroductive* reasoning schema, and claimed that it could give an adequate account of Kepler's

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<sup>3</sup> Eight minute discrepancy was not serious according to the standards of previous astronomical tradition. Here the accuracy of Tycho's observations is crucial. Previous astronomist from Ptolemy to Copernicus used essentially the same data in which the size of errors could be around ten minutes of arc. Tycho's data contained only two to three minute errors.

reasoning which, according to Peirce, is "the greatest piece of retroductive reasoning ever performed."<sup>4</sup> Abductive reasoning conforms to the following schema (Hanson 1958, p. 86):

1. Some surprising phenomena P is observed.
2. P would be explicable as a matter of course, if H were true.
3. Hence there is reason to think that H is true.

Hanson characterizes abductive reasoning as follows (1958, p. 90):

Theories put phenomena into systems. They are built up "in reverse"- retroductively. A theory is a cluster of conclusions in search of a premiss. From the observed properties of phenomena the physicist reasons his way towards a keystone idea from which the properties are explicable as a matter of course.

Hanson further argued that abductive inference could help the inquirer to see general intelligible patterns in the evidential data. What this seeing comes to is a kind of "conceptual Gestalt-switch": the puzzling and confusing phenomena appears suddenly as a systematically arranged pattern. This is achieved by inventing a hypothesis which explicates or explains the data "as a matter of course."

In Kepler's case, the conclusion of the abductive reasoning says that the Martian orbit is ellipse. According to Hanson, Kepler derived this conclusion from Tycho's observations. By employing abductive reasoning, Kepler could finally see the right pattern in Tycho's data, and discover the correct elliptical form of the Martian orbit. However, it is easy to see that this account would not do the trick. For one thing, the role of background knowledge should be made more explicit. As we saw, in addition to Tycho's observations, Kepler adopted and modified planetary models which were originally invented by Ptolemy, Copernicus and Tycho Brahe, his predecessors in the astronomical tradition. These models constituted the store of background knowledge which formed one central element in Kepler's inquiry. In the later phases, Kepler's own physical theory was an important element in his background, providing criteria by which he could evaluate the different versions of planetary models.<sup>5</sup>

Apart from this, Hanson's account does not capture anything from the dynamics of model revision. We could perhaps try to reconstruct parts of Kepler's reasoning by the following modified abductive schema:

(AB)

1. The predictions of model M[i] deviate from observations in such and such way.
2. If the modification of M[i], M[i+1], were true, observations would follow at least approximately and the previous deviation would be explained.
3. Hence there is a reason to think that M[i+1] is true.

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<sup>4</sup> See Niiniluoto (1999), and Kapitan (1992), for a discussion of Peirce's view of abductive inference.

<sup>5</sup> In his later writings, Hanson gave much more weight to the role of background knowledge in the abductive reasoning, but he did not give new treatment of the Kepler-example (e.g. Hanson 1965). Kleiner (1983) tries to improve Hanson's account. He emphasizes the role of background knowledge, and contends that Kepler's background assumptions were largely fixed before his "war on Mars" even begun. In *Mysterium Cosmographicum*, Kepler already adopted the methodological maxims which, according to Kleiner, form the background of his war. To be more precise, Kleiner claims that these maxims form a metaphysical blueprint in a sense of Maxwell (1974), and that Kepler's reasoning in *Astronomia Nova* accords with the rules of rational assessment of metaphysical blueprints given by Maxwell. These rules offer criteria for preferring some hypotheses and research programmes over others.

This schema could be applied to some (but not all) phases of Kepler's discovery process. For instance, the reason to replace M[1] with M[2] does not accord with the above schema. Kepler abandoned M[1] because he thought that it was physically unrealistic. There were not any equant points in the physical space. But (AB) can capture something of the empirical reasons to replace M[2] with M[3], and of the reasons to abandon M[3] and construe another model M[4]. However, even in these cases it cannot capture all the important details about Kepler's hesitations and false starts in the creation of improved models.

Hence, the story is much more complicated than Hanson's simple abductive account could tell us. Ironically, it seems that Hanson, despite his critical view, was himself mostly confined to the logic of finished research reports. His simple abductive model could only summarize the barebones of the final stage in the Kepler-example.

And let me emphasize that even our revised and more realistic abductive account (AB) is far away from the realistic story of Kepler's inquiry. There are aspects of Kepler's reasoning which simply do not conform to the abductive schema. Why he, for instance, was dissatisfied with M[1] although he could explain observations by it? The simple answer is that there were gaps or inconcistencies in his background knowledge which did not directly concern the explanation of observations. Besides this, his problem solving involved numerous patterns of reasoning. Snyder (1997), for instance, finds from *Astronomia Nova* instances of enumerative induction, eliminative induction, causal and analogical reasoning. Also Lugg (1985) argues that although Kepler always gave reasons for his decisions, the micro-structure of his problem solving does not conform to the simple rules, since "it involved exploratory forays, preliminary skirmishing, the repairing of broken flanks, holding actions, and attempts to capitalize on limited successes" (pp. 215-6).

There is a possibility to interpret abductive account as an idealized summary of the complex process in which unimportant details are ignored. On this picture, it is a shorthand for the more complex process, and could help us to see, for instance, certain essential phases in the overall discovery process. Thus (AB)-schema above could provide us important information about Kepler's discovery even if it does not tell the whole story. We could perhaps construe such idealized reconstructions, but if the goal is to find out how the discoveries were actually achieved, it is difficult to attach any rationale to this attempt.

Another strategy is to augment the basic abductive pattern with a list of methodological rules and other heuristic principles which guide the search of explanations (simplicity etc., cf. Kleiner 1983). But in this case too, it is very difficult to give a general list which would cover all the relevant cases, not to mention the fact that these kinds of lists are dependent on the factual knowledge, the current stage of science, and are likely to evolve with time. There is also a danger of *ad hoc* theorizing if we only add elements to our putative general model of discovery whenever they are needed without giving them any independent justification.

To come to the conclusion, we have seen that in the case of at least one complex example the abductive model could not capture the details of the process of discovery. Explanatory hypotheses are somehow invented, but the abductive model is not able to show in any detailed way how this is actually done. Thus abductive reasoning is like a black box which absorbs the evidence and outputs the explanatory hypotheses. It is very difficult to give any general account what happens inside the box.

My hunch is that abduction works as a model or account of discovery only at the abstract level or with relatively simple and well-defined examples. If we try to fill up the details of complex

discovery processes, like in the Kepler-example above, the whole approach becomes either inaccurate or uninformative, since it is either unable to capture all the historical facts or confined to the idealized reconstruction. When we focus on the details of problem-solving, the general heuristic to simply search for hypothesis or model which explains the evidence is not so interesting anymore. It is like saying to the thirsty man who is lost in the desert that go and try to find water. In other words, when the black box is opened, the general characterization could become futile.

This is not to say that abduction as heuristic tool could not be important in some cases. In many cases, we do not have enough knowledge of the historical facts to fill up the details of the reasoning process. In these cases, the more general and vague guidelines offered by abductive reasoning could be all that we could say about the discovery of explanatory hypotheses. The importance of Kepler-example is just that it is based on so extraordinarily detailed (and relatively reliable) description of the complex reasoning process that it can show the limitations of abductive approach as a heuristic tool of discovery.

These worries reflect the more general argument according to which the application of normative methodological models to the history of science could lead to unnatural situations and *ad hoc* theorizing. We have to make conventional decisions of which facts are relevant, which rules or principles were applied and so on.<sup>6</sup> There is a dilemma that if we try to use a simple model (like the abductive one) it could not accurately describe historical details. If we choose a more general and flexible model or ignore historical details, the result could be, respectively, loaded with *ad hoc* elements or uninformative.

### **3. IBE and the Justification of Kepler's Ellipse**

I have so far discussed the application of abductive inference to the complex discovery process. What about IBE? Does it bring new elements to the discussion? Although IBE is more explicit what comes to the role of background knowledge, for instance, I think that as a model of discovery it is on a par with the abductive model. It does not have resources to handle the Kepler- case more realistically. But what about justification? I will briefly argue that this is a more promising way to apply these models. This is not, of course, in any way new or surprising result, since it is in accordance with the standard interpretations of abduction and IBE in the literature.

Abductive model is often seen to provide some kind of initial plausibility or justification to its conclusion. It does not give a logic of discovery but may give some kind of logic of pursuit or preliminary assesment. However, if a task is to show why it was reasonable for the inquirer to adopt a hypothesis, IBE could be the more interesting approach. On this picture, it is a kind of contextual model of justification (cf. Ben-Menahem1990, Day and Kincaid 1994).

Was Kepler justified in his belief that the Martian orbit is ellipse? In this task we could forget for the moment the chronology of the discovery process, and just examine whether the final model M[4] constituted a better explanation than its rivals M[1], M[2], and M[3]. At first it seems that we could not apply IBE to every phase in Kepler's discovery process, since the point of IBE is to choose the best explanation from the ones that all explain the same evidence. Kepler rejected

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<sup>6</sup> See, for instance, Thomason's (1992) critical discussion of Lakatos' and Zahar's attempt to employ Zahar's notion of novel evidence to prove that Copernican research program was more progressive than Ptolemy's, and Shananan's (1997) critical attempt to apply Philip Kitcher's (1993) compromise model of scientific closure to the group/genic -selectionism debate of the 1960's.

some of his models just because they could not explain all observations with the demanded precision. But an alternative way is to contend that all models explained the evidence but some of them made it with greater precision, and it was just this feature which made them better explanations. In the following, I will adopt this latter interpretation.

Of course, Kepler did not have any specific explanatory models in our sense. But when he weight alternative ways to develop planetary models, he used various criteria to distinguish acceptable or promising elements and lines of arguments from the non-acceptable or less promising. These ranged from the general methodological principles to the highly specific evaluations of the reliability of geometric techniques, and even more or less idiosyncratic metaphysical and theological views played some role in his thinking (see Kozhamthadam 1994). The constraints arising from his physical theory were especially important. The best explanation in Kepler's sense is the one which satisfies as many as possible of these requirements. The ellipse-based model M[4] was the only one of which all the observations could be predicted with enough precision and which also was in accordance with Kepler's physical astronomy. Given Kepler's background assumptions, it provided the best explanation of the evidence.

Here is a simplified reconstruction of Kepler's reasoning:

1. M[1], M[2], M[3] and M[4] explained Tycho Brahe's observations.
2. Kepler thought that M[4] provided a better explanation than M[2] or M[3] because its predictions (i.e. the calculated orbit of Mars) captured all observations with demanded precision. This was not the case with the predictions of M[2] or M[3].
3. Kepler thought that M[4] provided a better explanation than M[1] because the former did not employ physically unrealistic geometric devices and was in accordance with his physical astronomy.
4. Hence Kepler accepted M[4] as true.

What about the credentials of Kepler's reasoning? Does it justify the result that the orbit of Mars is elliptical and that Kepler's physical *cum* geometric model M[4] correctly describes its path as well as the forces behind the planetary motions? It does with respect to Kepler's own background knowledge. It does not with respect to our current knowledge of the situation. Kepler's inference to the best explanation provides only contextual credibility to M[4]. As such, the conclusion of IBE is not very deep or surprising result: it only shows that Kepler adopted the model which best coheres with his background knowledge and evidence. It would have been very unreasonable if he had not followed this policy. On the other hand, the IBE -account could show why Kepler's discovery was not merely a guess (as Newton famously claimed) but a justified result which was based on a coherent world view, strict methodological standards, and sound reasoning.

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