14 Galileo and the Telescope Do Instruments Discover the Facts that Prove Theories ?

In this Chapter, and the last two Chapters on Kepler and Tycho Brahe, we are trying to tackle two problems. In all three cases we will have looked at the individual's work in the Copernican debate and in each case we will have been isolating one aspect of their work to show some general sociological/political aspect of science. With Tycho it was the professional negotiation of theory claims; with Kepler it was the nature of scientific discovery as intellectual construction within a metaphysical context and web of research priorities, and here we will look at Galileo and the telescope. (We will be hearing more about Galileo and the Church later on). We will look at politics and the theory loading of the use of instruments in science.

In 1609 Galileo had yet to emerge in public as a Copernican, although he was indeed a Copernican. He had received a report about what we would now consider a telescope, which as a device had been used for a number of years in the Low Countries--the Netherlands--where it had apparently been invented. It was used primarily as a toy and as a kind of secret military technology. It was obviously a useful military aid before battles and on the battlefield itself. Lenses and glasses had been invented before this period in the Middle Ages and they had been discussed by medieval Natural Philosophers. But the telescope had not been. Galileo did not initially receive a telescope, he had to build one, through trial and error, because he had no theoretical understanding of how or why a telescope worked. He became the second man, after England's Thomas Harriot (who did not publish), to apply the telescope to the heavens.

Galileo's initial discoveries were reported in two publications, *The Messenger of the Stars* (1610) and his *Letters on Sunspots* (1613). Later, toward the end of his career, he summarised and made more powerful use of his observations in favour of Copernicanism in his *Dialogues Concerning the Two Chief World Systems* (1632). This was the book that got him into trouble. The two chief world systems were supposedly Aristotelian and Copernican. (Pretending that the Tychonic system is not important in true Whiggish fashion.) Galileo presented and used his telescopic observations in an attempt to establish that they virtually ruled out of court the Aristotelian system and they virtually established the Copernican system. Many commentators, since Galileo have swallowed Galileo's tactics, accepting his claim that his observations rule out Aristotle and rule in Copernicus (ignoring Tycho's claims).

We will first look at Galileo's observations (his way) and then we will look at them in perhaps the way a more sceptical contemporary of Galileo would have looked at them. Then we are going to open up a set of problems about what the telescope was doing and how Galileo was using it. By doing this we are going to learn that the idea that scientific instruments simply capture and clarify facts that are coming to us from nature is not sustainable; and that the idea that instruments simply make independently existing facts more readily available is not sustainable. (cf fig 5 below) We shall see that we need a more up to date history and sociology of science viewpoint about the role of scientific instruments and scientific work. Galileo's story shows us some of that. Towards the end of the Chapter, I will make some comments about Galileo's undeserved success in persuading the educated public that yes, indeed, Aristotle had indeed been severely wounded by his evidence and Copernicus had been very powerfully supported by his evidence.

Galileo's main 'discoveries' fall into five categories and I am going to treat them in three sub-categories. The first two I am going to call quantitative results; the third and fourth I am going to call qualitative results. The fifth result, the discovery of the four moons of Jupiter, which is a kind of qualitative result, I shall comment upon separately.

First, the Phases of Venus: (fig. 1) In the Copernican system, as Copernicus himself well understood, Venus should show to an observer on Earth phases rather similar to the phases displayed by the moon, because venus goes around the sun and the earth moves on a more distant orbit. Sometimes, as seen from the earth venus is going to be completely lit up by the Sun on the side facing the earth, and venus will display a full disc to the observer on earth. In other alignments of the sun, earth and venus the observer on Earth is going to see only a part of venus: a slither, or a half or a crescent depending on the position. Indeed you can geometrically predict what you should see, because you have the relative distances amongst the bodies according to Copernicus as well.

Unfortunately for Copernicus, no phases of venus can be seen or at least be seen with the naked eye. (This was a 'false' prediction of the Copernican system!) No phases of venus were seen until 1609 when Galileo observed the phases of venus and this was very exciting for him and to anyone who understood the issues at stake. In fact Galileo in his writings about this praises Copernicus for ignoring observations that threatened his theory. Galileo states that Copernicus followed "reason" and not the senses and he goes on to say that the telescope gives a surprising and better 'sense' which actually reveals the facts of Copernican theory correctly. These gentlemen could hardly be called Popperians, for Copernicus is being praised for his rationality, for not rushing out to cancel his theory when his observations did not support its predictions! You might be interested to know what Copernicus had said about the non-observation of the predicted phases of venus in his time. Well, I do not think Sir Karl Popper would have been impressed, because Copernicus argued as follows: he said that venus was transparent. That's what I call adjusting the theory to save it.

Next, the changes in apparent disk size of mars and venus: Another interesting aspect of the Copernican system is that because it gives the relative sizes of the orbits, it can predict the ratio between the maximum and minimum earth-venus and earth-mars distances. Let's consider the former: It follows from the Copernican theory and in fact the theory says, that venus is going to be six times further away at its furthest distance, than it is at its closest point to earth. The ratio here is 1:6 (fig. 2) and that is a firm consequence or prediction of Copernican theory. Now you know that when you look at something and it is six times closer--that means its length has increased six times, and its width has increased six times, so its apparent surface area has increased 36 times. In other words, it's a prediction of Copernican theory that venus at its closest approach to earth will appear 36 times bigger than when venus is furthest from the earth. So we have a prediction of a ratio of 36:1 in apparent disk size.

The same argument can be applied to mars, for it comes even closer to the earth and goes even further away. The ratio is about 8:1 so in terms of the apparent disc size the ratio is about 60:1. When mars is closer to the earth, it should appear 60 times bigger than when it is far away from earth.

These are indeed dramatic predictions and like so many dramatic predictions of the Copernican theory, apparently completely false in terms of naked eye observations. Because naked eye observations reveal ratios on the order of about 4:1 for mars and 1:1

for venus. So the former figures are the Copernican predictions and the latter figures are the naked eye observations of people like Tycho Brahe. But Galileo looks through his telescope and claims he sees an apparent increase in size for venus of about 40:1 and an apparent increase in size for mars of about 60:1. Given all the problems the Copernicans had before, these figures are "good enough". Remember there is always the issue of the figures being 'good enough'. The telescope "confirms" the predictions of the Copernican theory. The facts establish the truth of Copernicanism as far as Galileo is concerned.

Let us turn now to the 'qualitative evidence', which did not so much confirm predictions of Copernicus as undermine the principles of Aristotle. There are two main results here: the first is that the Moon has an Earth-like surface. It does not seem to be a perfect celestial entity, it seems to have mountains and valleys and oceans. That is what Galileo reports. The conclusion that he draws from this that the Aristotelian distinction between 'celestial' and 'earthy' is wrong. The Moon is like the Earth and vice versa. This is excellent if you are a Copernican, because you view the Earth as being up in the heavens spinning around. It's a heavenly body. This is evidence against Aristotle.

The second piece of qualitative evidence deals with sunspots: The sun has spots, naturally occurring huge magnetic energy storms on its surface which can affect radio reception and communications on earth. Galileo observed the sunspots and very cleverly and correctly concluded that they are not in the intervening space but are on the surface of the sun. (Kepler also predicted this). Galileo did not wear sunglasses whilst he did this and he eventually went blind. So as an old man in the 1630s, and at his trial, he was close to blindness and later completely blind. Anyway sunspots tend to show that the sun, this most wonderful and noble object in our solar system, is also subject to corruption, decay and imperfection. It's not overwhelmingly crushing evidence, but it is not something that the Aristotelians would be terribly glad to hear about.

Finally we come to Galileo's most famous observation -- that Jupiter has four satellites. This is an interesting story, not least because Galileo literally auctioned off the right to have the moons named after oneself. Galileo really needed a change of job; he wanted to get out of the University of Padua and work for a private patron, so to gain these ends he 'huckstered' these satellites to various princes and monarchs of Europe offering to name the planets after whoever would give him a job. He eventually persuaded the 12 or 13 year old Grand Duke of Tuscany, the Medicean prince of Florence gave Galileo a job and a raise. So those moons were named the Medicean planets.

What, then is the meaning of the four moons of Jupiter in the Copernican debate? Well, I have trouble with this and I can't really see the point: perhaps Galileo's rhetoric is especially weak at this point. What Galileo says is: In the Copernican system the Earth's moon goes around the Earth and the Earth goes around the Sun. So the Earth's moon has a composite motion. It goes around the Earth whilst it goes around the Sun. Now this might bother you but it shouldn't bother you because Jupiter has moons too. Later Whiggish historians of science have also picked up on his claim that the four Jupiter moons are a model of a Copernican system. Galileo argued that also. I don't know...I think he was just finding a way of cashing in on the dramatic value of finding these moons. He was trying to make them mean something - but they don't mean that much in the Copernican debate.

So much for Galileo's presentation of his 'facts'. Do we need to be convinced? Are these straight out facts of the natural order or are they argumentative interpretations of things perceived; are they tactically and rhetorically structured reports which are 'bidding' to be accepted as facts. A Tychonist, for example, would find a great deal of support in these findings, especially the quantitative ones. And the leading Tychonists knew it. Some of them were the leading Jesuit astronomers of the Church and they were very unhappy with Galileo's claims and theorising. As we know, it just so happens that the Tychonic system is geometrically equivalent to the Copernican system--it had all the original Copernican harmonies built into it. So the Tychonic system also predicts the phases of Venus and it just so happens that the Tychonic system predicts that Venus will show a ratio of apparent sizes max to min of 36:1 and that Mars will show a max to min ratio of 60:1. It makes the same predictions as Copernicanism--quantitatively and so it is dramatically and triumphantly confirmed by Galileo's observations, although you would never guess this by reading his writings. So, it is not so much the single-minded triumph that Galileo makes it out to be.

Now what about the moon-scape and the sun-spots? These are an embarrassment for Aristotelians, especially the more strict ones who wanted absolutely no change up in the heavens. But Tycho had observed a supernova in 1572 --a change in the heavens. And Tycho had done away with the perfect hard crystalline spheres in favour of an ethereal liquid. In 1577 Tycho had observed a comet go through the heavens where spheres should have been, so a Tychonist could easily say, look the old terrestrial/celestial distinction is a little bit fuzzy, so we can live with these results of Galileo. It's not terribly great positive evidence for Tycho, but there is nothing really dangerous in a moonscape. And the moons of Jupiter are a bit of a beat-up for they are just doing in the Copernican system what the planets are doing in the Tychonic system, that is they revolve around something else whilst they revolve around the Earth. . So there is not as much in it as Galileo or some of the Whiggish writers you will meet, make out.

So, in all this we have really been talking about the interpretation of evidence which appear in the form of those 'reports' we discussed in general in chapter 2: How do we pick up and interpret the evidence and feed it into our arguments. Galileo takes evidence that is useful for Tycho and tries to pretend that it virtually proves Copernicanism, by taking Aristotle as the only contender to be defeated.

But there is something else involved here in Galileo's argumentative tactics. I will call this something 'the selection of evidence', and obviously interpretation and selection of evidence, interact. But there is also selection of evidence because the phenomena discussed so far are not the only phenomena arising from the use of the telescope. They have been selected by Galileo as the most favourable to be interpreted by him, but there is other evidence that can be selected and interpreted.

Let's begin to look at this by inspecting one of Galileo's diagrams (fig. 3). This is his sketch of what he saw. Note the jagged edge between the dark and light regions of the moon--the jagged edges are said to prove that the surface is rough and that it has valleys, and mountains and craters. But look at the outer edge, it is a spherical moon and he describes it as such.

Now let's go back in the story. In 1604 Kepler published a very important work on optics and in this work he says that the line between light and dark on the moon looks a little wavy and that the edge of the moon doesn't look circular to him the naked eye. Kepler has then already said that the edge of the moon looks rough. Galileo chooses, as he did with so many things that Kepler said, to ignore it.

There is a very important reason why he ignores it, for there is the very important issue of selection at stake here. Galileo has published his diagram and description and he sticks with it, and he does not correct it. If he corrected it he would be correcting his views on the basis of naked eye observation and he does not want to correct his observation on the basis of the naked eye observation, because he wants to stick with the idea that the telescope is the supreme and hegemonic instrument. The naked eye doesn't correct the telescope the telescope corrects the naked eye. So even in this case where it could have been usefully corrected, he refuses to do so.

Given this Galilean principle of selection, we should also look at a photograph of the moon (fig. 4). It is the same region as in Galileo's sketch. I take it that the crater in the photo on the light/shade dividing line is the one Galileo represents by a huge crater on his sketch. As one modern expert says, "none of the features [of Galileo's sketch] can be safely identified with any known [modern] markings of the lunar surface". In fact, the thing Galileo draws is so big that if it existed, it would be visible with the naked eye! So again, the naked eye cannot correct the telescope, but the telescope is not entirely reliable. This question of not being certain of the limits of reliability of the telescope gets worse.

For example, if you look at the fixed stars with your naked eye, you see a little kind of scintillating splotch--you don't usually see a nice clean dot of light--but if you look at the same star with a Galilean telescope of magnification about 30, you see a point of light. The planets are magnified, the sun is magnified, and the moon is magnified. And as for objects on the Earth, they are magnified, because we can go and touch them after we have looked at them in the telescope. But, the stars are made smaller. Galileo knows that and he tries to explain it: When you look with your naked eye there is a kind of irradiation of light on the surface of your eye and inside your eye which spreads out the image but when you look with the telescope for some reason you do not get that spreading of the light by irradiation in your eye, so you get a point image of the star. So he explains away the behaviour of the telescope in this case. By the way, that problem of irradiation is still not definitively solved and it is a problem of human perceptual physiology and psychology.

From all this we learn an important point for the history of experimental science: Ultimately the use of an instrument depends upon how you theoretically interpret its makeup, its output and its reliability of performance. You can't just use an instrument without having such theories about how it works. The appearance of stars was a problem, an anomaly and Galileo had to explain it away. A lot of people were convinced by his theory and 'bought it', but in principle the telescope was working in at least a questionable way but Galileo was pretending that it was completely understood and reliable across the full range of its applications.

So there is the problem of selection and interpretation (presentation) of evidence and also the problem of the theory of instruments. In a way Galileo is working with a very common, even to this day, notion of how instruments work. A naive theory of instruments states (fig. 5), that there is first of all nature; nature sends facts to us; and we use instruments to sort, isolate and clarify the facts; and then finally we use the facts to test theories. You can match up a fact to a prediction and your theory is then either right or wrong based on the fact. Instruments, then, on this view are theory-neutral aids to getting the facts clarified or isolated. That's the very common understandable statement about what instruments are. In effect Galileo is saying that: "don't worry about how the thing works; it is better than my eye sight; it is reliable (that means reliable where I choose to be reliant upon it and ignore it where I choose to ignore the problems)". That's the naive and the Galilean theory of instruments. We will return to a more sophisticated theory of instruments in a moment.

For the moment, having looked at the interpretation and selection of evidence, we shall look at the larger issues; what the evidence means to an audience, what it would have meant to you if you had been part of the debate. Twice in the period 1610-11, Galileo presided over telescope parties where his friends and some of his enemies were invited to the house of a nobleman. A telescope would be set up and everyone would be invited to look through the telescope and see these discoveries for themselves. This was part of Galileo's overall campaign for Copernicanism. On one of these occasions we know (for it was reported by one of his friends) that no one could see the moons of Jupiter except Galileo. Now I am not saying that the moons of Jupiter don't exist or that Galileo didn't see them. What I'm saying is that when you look at objects that are not earthly objects (because with *them* you have all kinds of everyday clues to back up what you are looking at); when you are looking at objects that are strange and unusual through a telescope, it is easy not to see, or to be confused about what you see, or to see something that some other people will not agree to.

There were a couple of Aristotelian professors present and they made the apparently very silly move of saying we are not going to look through the telescope. But even that position was reasonable because obviously the thing works in contradictory ways and as Galileo doesn't really know how it works, why don't you just take the position that until he can tell you how it works, you won't look through it. Because after all, if someone walked in the door and said he was going to give you perpetual motion so you would be able to get unlimited amounts of work out without any energy input, you would use your theoretical knowledge of physics to dismiss him *without even looking at his machine*.

When you look through a telescope and you are not looking at terrestrial objects but at objects that no-one has looked at before, all kinds of strange things happen. For example, Kepler saw square planets. Some people thought that the moon was inside the tube; for when you first use a telescope the psychological location of the image, not the geometric optics of the image, sometimes makes it seems as though the image is inside the tube. If you look at a mountain with a telescope and the mountain is far away, the mountain is enlarged, but you do not get a sense that the mountain has moved right near you--you have a sense that it is still at a distance. But, if you look at something like the moon and it is enlarged, you get this uncanny feeling that the moon has been moved about a foot beyond the end of the telescope for some strange reason. You do not have a psychological way of locating the image in a consistent or realistic way.

So people see strange things. Some of these problems are still unsolved. We use telescopes and we try to avoid those kinds of reports but some of the problems are still not completely solved by psychologists and physiologists.

There are some other problems about the telescope that were solved later. For example: if you look at an object through a telescope you will very often see little coloured fringes around the object. Kepler reported that his square planets were highly coloured--these are chromatic dispersion fringes. The theory of chromatic dispersion was first put forward by Newton to get rid of this problem in 1704. So after Newton you could use a telescope, and if you saw coloured fringes you could calculate them: how much was the coloured fringe a product of chromatic dispersion and how much was it really in the object. Again, in other words, we need theories to sort out what we are seeing through an instrument. Instruments do not fall from trees for they are made and used as the materialisation of theories. Instruments can only be used reliably when we have theories of how they work and we are all agreed upon them.

What was the state of theory of the telescope in 1609--virtually nil. In 1611 Kepler published a work on telescopes, but it was limited by the fact that he did not know the law of refraction of light. In 1637 Descartes published a work on refraction and telescopes and he did know a law of refraction of light, but he did not know about chromatic dispersion and there are many other things about telescopes that you need to know to use them reliably. So the telescope was first used in a theoretical void. The theory of the telescope has been developed along with the telescopes ever since that time. If you like, we could say: the telescope has a history for it didn't just drop from the sky one day and work. The theories of light, the theories of optics, the theories of physiology and psychology as they developed affected what 'the telescope' was taken to be and how it was thought to be able to used.

The telescope has a history which is partially explained by figures 6 to 8. The real situation for Galileo and his telescope, as with any theory or instrument, is that nature is out there exerting sensory pressure on us and our instrument. But, an instrument is a 'materialised' theory--just like a car engine is a materialisation of the principles of physics and thermo-dynamics and structure of materials and whatever else. You cannot make instruments without committing yourself to those theories. An instrument is a materialised theory--a theory made into hardware (fig 6). With instruments there is also a prior question: how does nature input our instrument for that always depend on the theory too? In this case light comes into our instrument. What is light? How does it bend? Is celestial light different from terrestrial light? etc. etc. So you need theory at the input end of an instrument. Instruments also give perceptual outputs--stuff comes out of instruments--but these perceptual outputs have to interpreted and selected--they still need interpretation and selection as we have seen in Galileo, so you need more theories. You need theories for interpreting and selecting perceptual output of a hardware or instrument. So, before you ever use this instrument to test a theory, you are going to need all the theories shown in fig 7. That is why science is so tricky and not easy, but when everything is stabilised and everybody is agreed, then an instrument is an instrument and it does what you say it does -- until further notice!

Finally, when you have interpreted and selected the perceptual outputs of an instrument you have 'data'. But we have been here before, we have been in the data prediction situation before, for even when you have got data (and now you understand what data is--it is the selected and perceptual output of an instrument which is a concretised theory), that data still has to be matched to predictions and they always leave a gap. And what takes place in the gap: interpretation, judgement and politics (fig 8). [cf Chapter 10]

Now, what was Galileo's result--what was the impact, especially of the early writings? To answer that, we have to be good social historians and segment the audience. First of all, expert followers of Tycho knew the evidence did not disqualify Tycho and that in fact, to a very large degree, it supported Tycho. Some of those expert followers of Tycho were people who were going to be very angry at Galileo later, like the Jesuit astronomers of the Church. But if you look not at expert astronomers, but at the educated public, then these works were very persuasive. The average educated man was not carrying on correspondence with Galileo the way that Kepler was, for they were not pondering the interpretation and selection of the evidence. The average educated person was very impressed and that just goes to show that good pieces of science follow very clever arguments and Galileo had put together a very clever interpretation and argument for what he was doing.

Now, what good did it do him that he persuaded a lot of people? In the short run, very little, because it gave him an over-confidence that he could actually finish the job of establishing Copernicanism and we are going to see how he got in trouble with the Church for pushing too fast and too hard on this issue. But, I would reckon, although it's a little bit hard to prove, that the greatest impact of these works of 1610 and 1613 was on the younger educated men throughout Europe. Men in their teens or twenties who in future years were going to be Natural Philosophers and partaking the larger Natural Philosophical debate: Which system of Natural Philosophy is correct? Amongst the future pioneers of the so-called Mechanical Philosophy there are a number of people who are quite young at this point who were impressed by these things. When we come to the Mechanical Philosophy, in the 1630s and 40s, we will find every one of those individuals is a Copernican. In a sense the battle was won quietly behind the scenes over a period of years, because by the time every new philosopher is committed to Copernicanism, the game is over. The technical arguments can go back and forth but Natural Philosophy has become Copernican.

So there is something really important about Galileo's telescopic works-- it convinced a lot of laymen, especially younger laymen who were going to be important thinkers later. It did not win a battle in 1613 and if anything it helped get Galileo personally into deep water later in his career. So there is a bit of irony here and a tragedy that Galileo was in the long-run successful, but in the short-run, personally, he got into a lot of trouble. In any case he was ultimately successful in a way that was probably not quite justified according to the standards of the time. You have got to be aware of something here--his evidence escaped the possible criticisms and the possible scepticism that an aware contemporary could have made against him and yet only a few contemporaries did make against him. But don't tell me that he proved the Copernican theory was true because that is not what he did. He persuaded a lot of people and it made a difference later. Galileo's arguments were selective and interpretive, rhetorical, dodgy and could have been knocked down better than they were.

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So, scientific knowledge, and scientific change are the result of debate, negotiation and persuasion taking place over time in quite possibly segmented but interacting niches of activity. Even instruments, their use and meaning are involved in those debates, not outside of them, so scientific knowledge and scientific change are not the result of good guys seizing instruments and peeping more accurately and definitively at Nature.

Figure 1

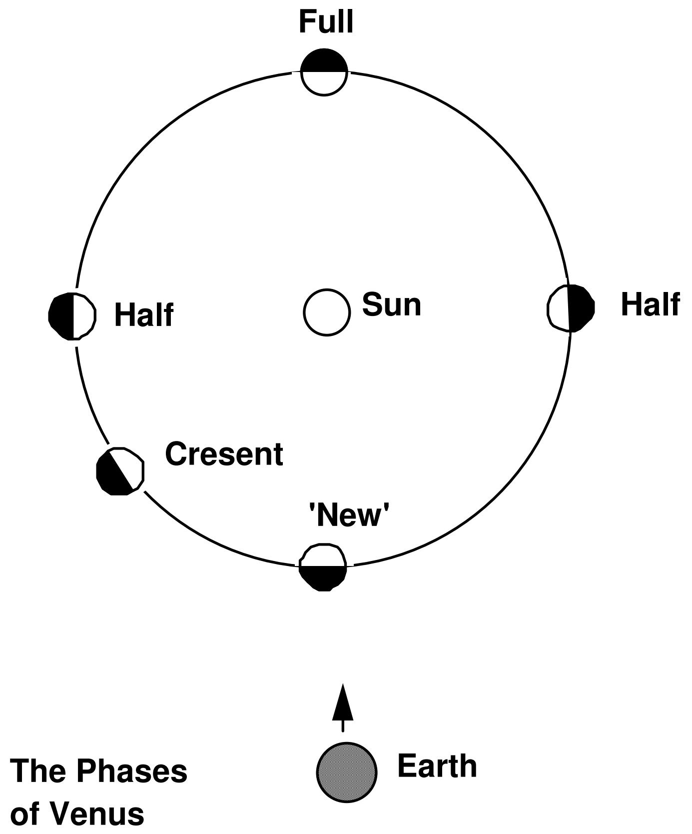
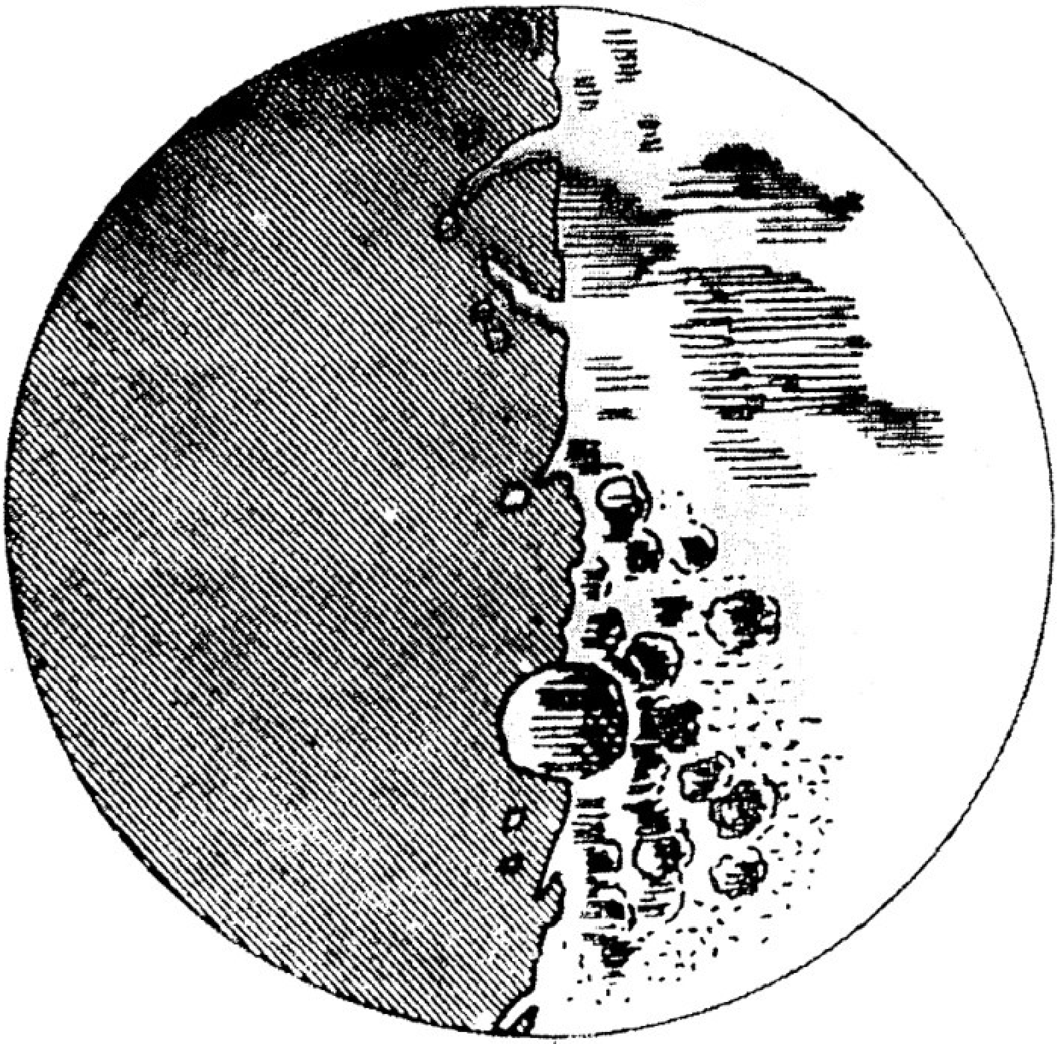


Figure 2

Changes in apparent disk size Venus/Mars

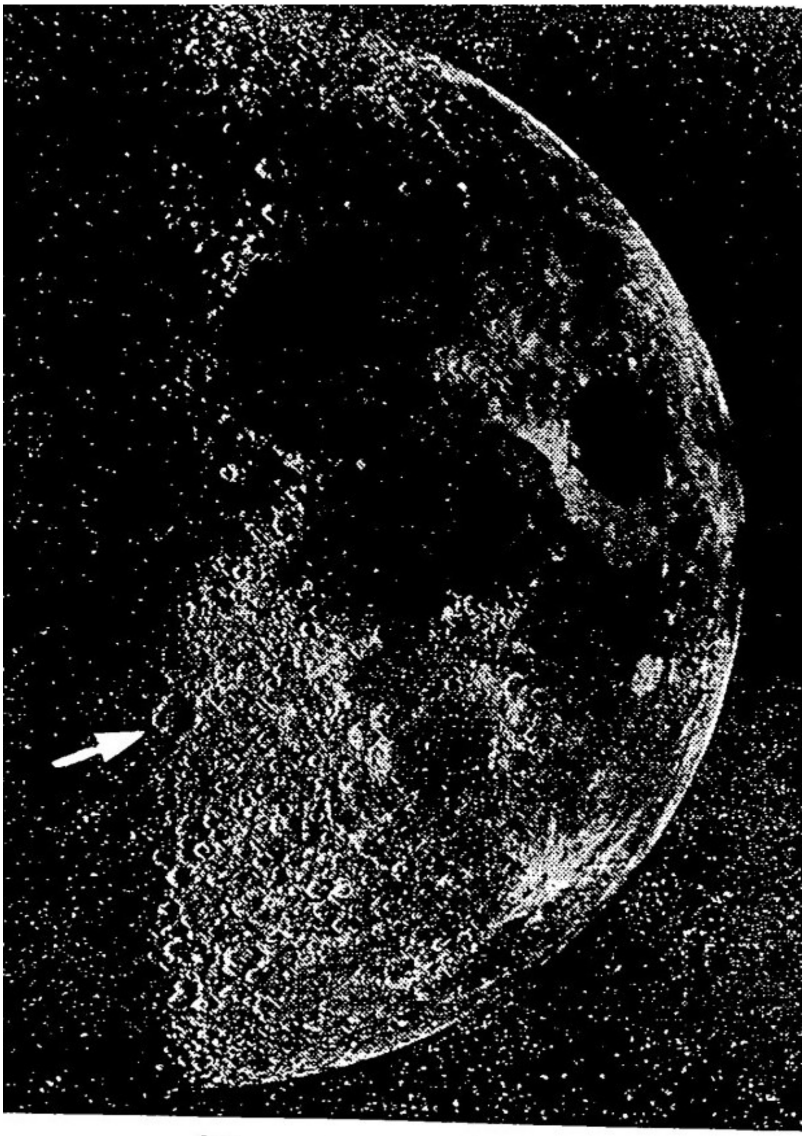
	max/min dist	apparent disk	Observed disk ratio
Venus	1:6	1:36	1:1
Mars	1:8	1:64	1:4

Figure 3



The shape of a lunar mountain and a walled plain, from Galileo, *Sidereus Nuncius*, Venice, 1610 (cf. p. 150).

FIGURE 4



Moon, age seven days (first quarter).

Figure 5 Naive View of Instruments

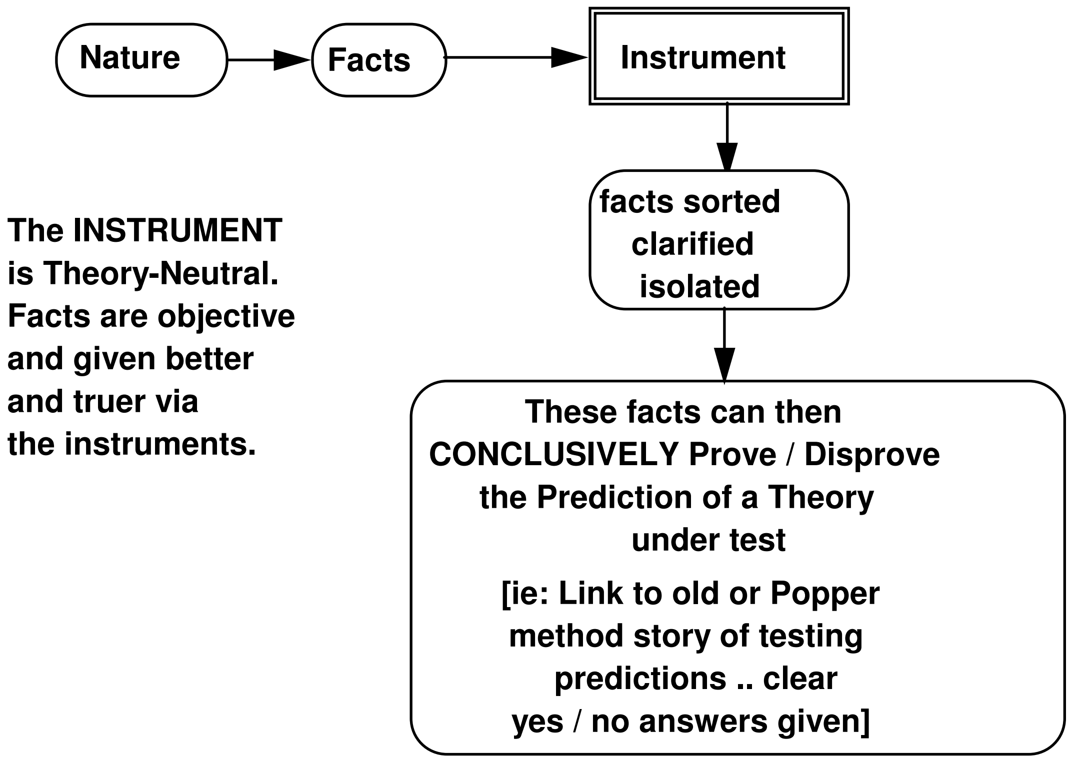


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Figure 6 Sophisticated View of Instruments

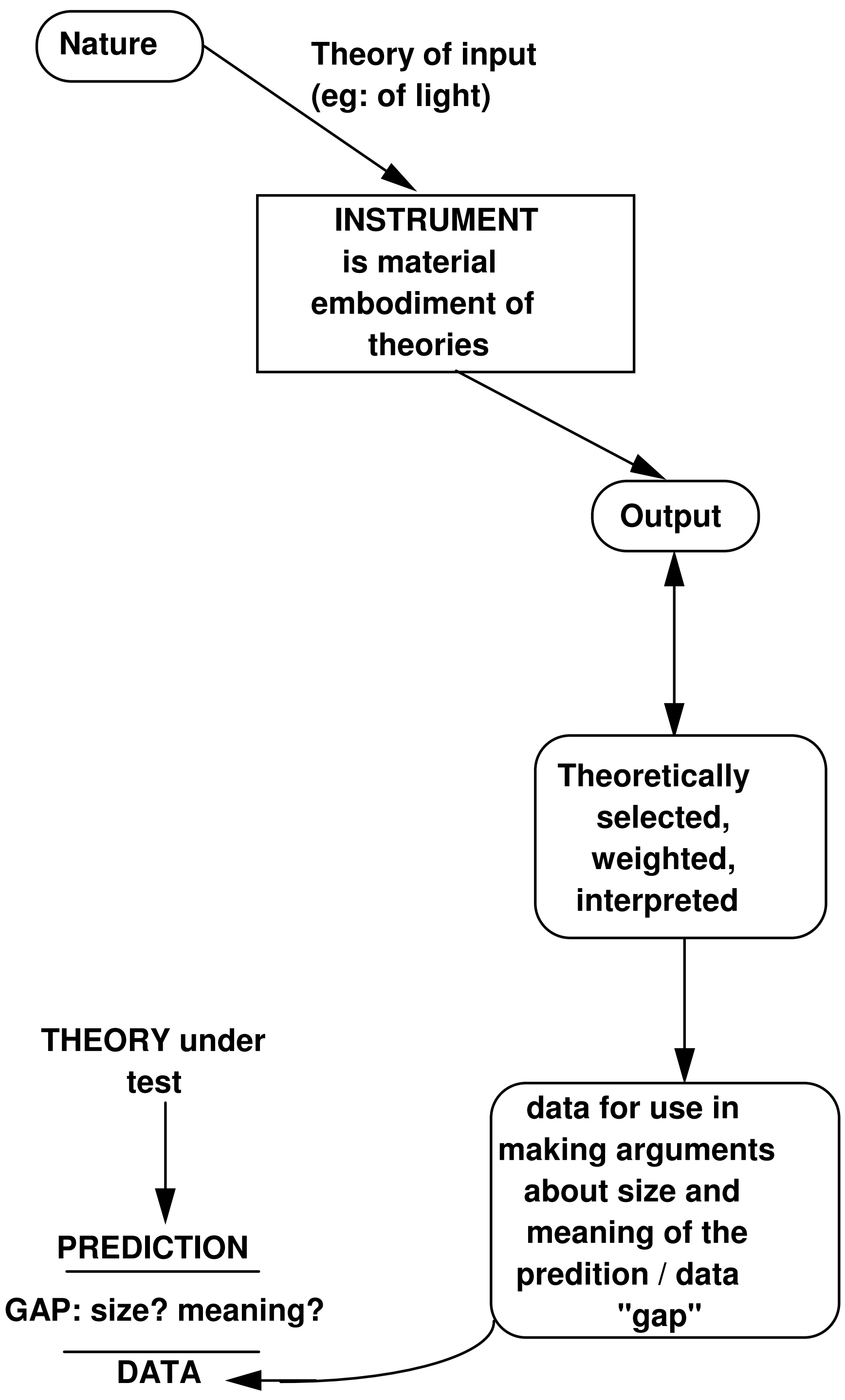


Figure 7 Sophisticated View of Instruments

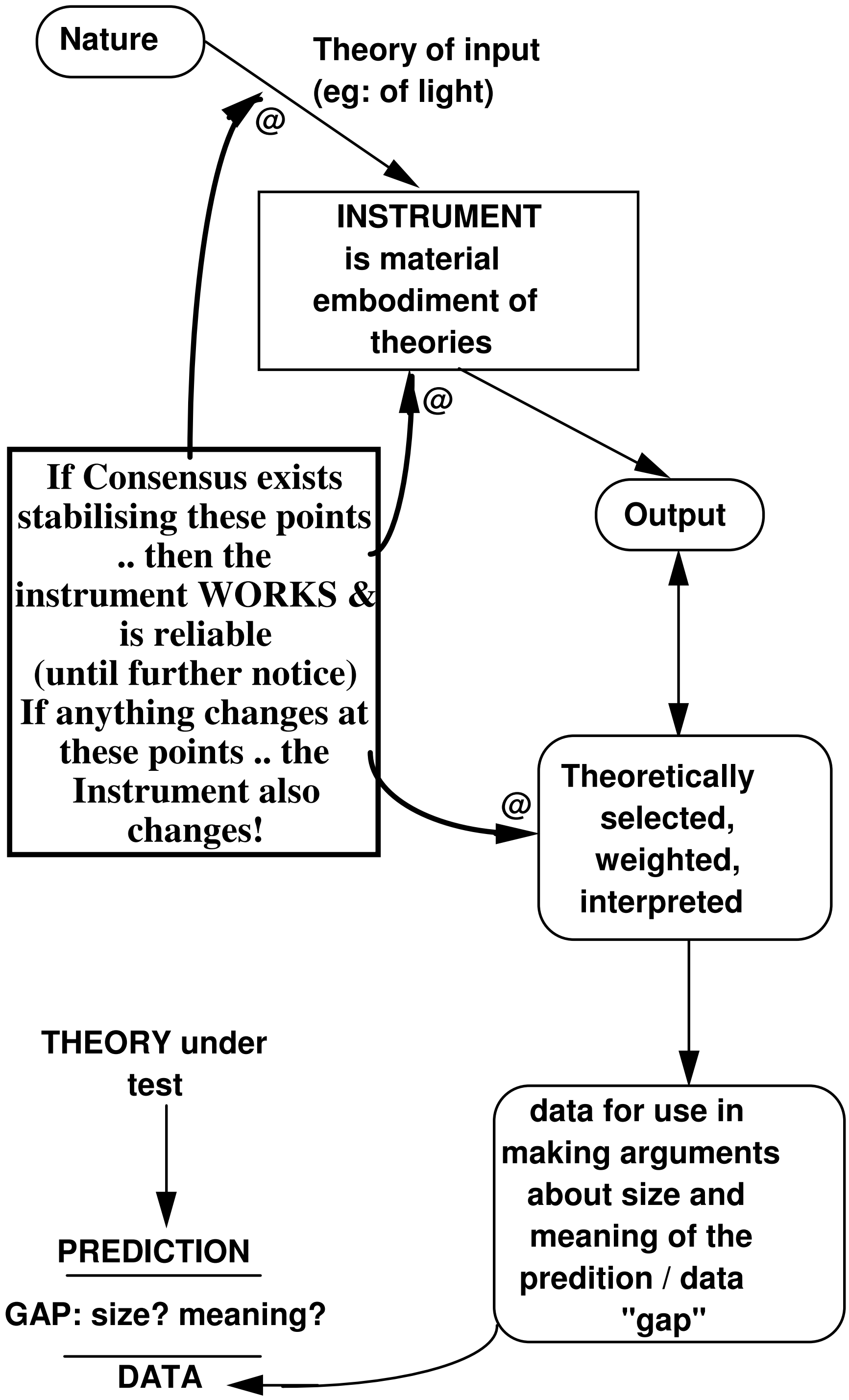
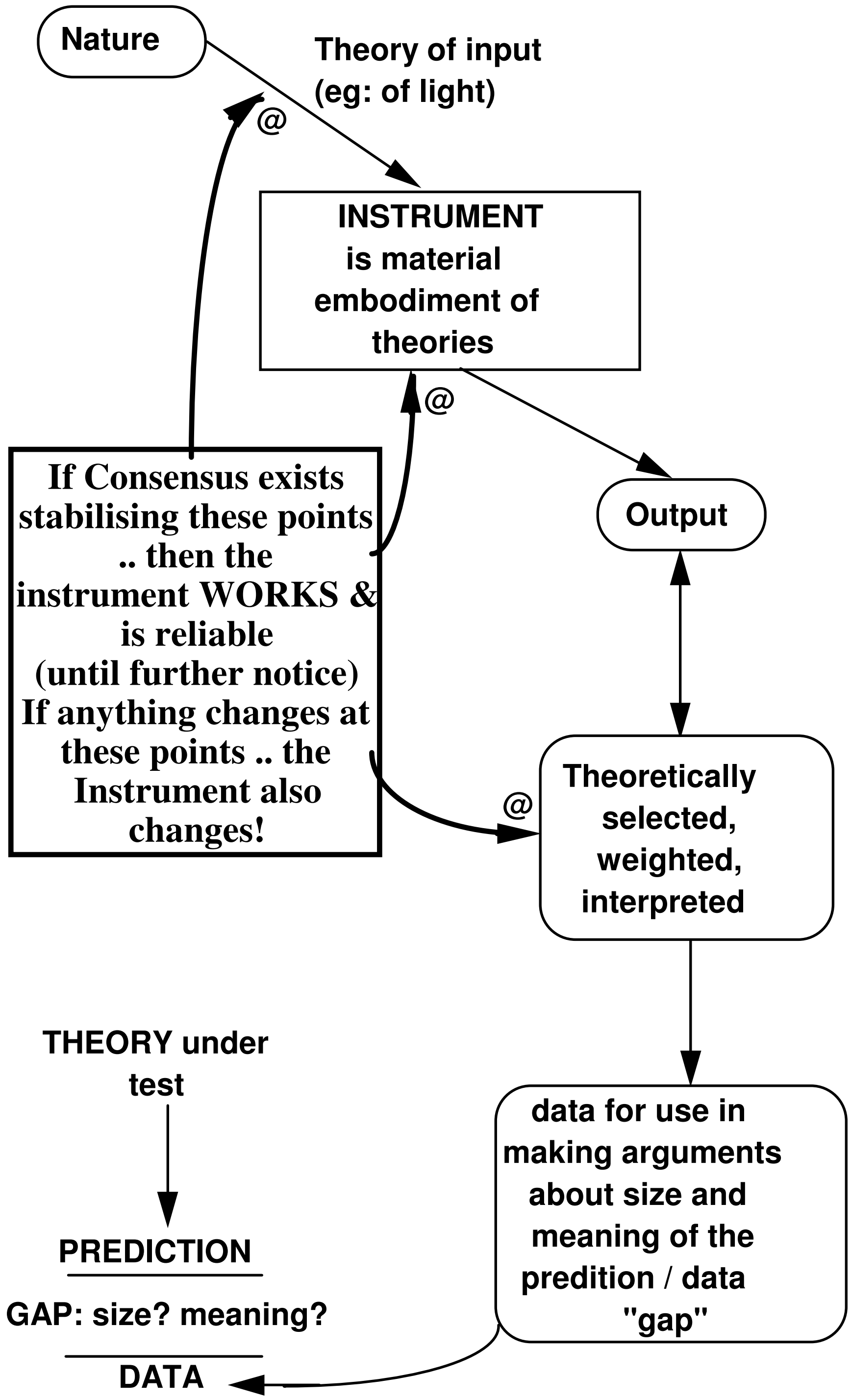


Figure 8 Sophisticated View of Instruments



How to narrow the PREDICTION/DATA GAP
change or modify:

* **Theory under test**
* **Prediction (modify other assumptions, approximations)**
* **Data (modify selection, interpretation weighting of outputs)**
* **Instrument (ie theories at points "@")**