7 Copernicus I: What He Did and What He Did Not Do

In 1543, on his deathbed, the Polish Astronomer Nicholas Copernicus was presented with a just published version of his book, *De Revolutionibus Orbium Caelestium*, or in English 'Concerning the Revolutions of the Heavenly Spheres'. In retrospect this was probably the first shot in the Scientific Revolution. Copernicus had waited 25 to 30 years to publish this book and almost didn't live to see it published. He had doubts and hesitations, scientific and religious (although the latter should not be overstated). In his book he made a revolutionary claim in astronomy. He believed that there would be a much better theory of astronomy if we accepted that the Sun is the centre of the planetary system and that the Earth is a planet orbiting the Sun every 365 days; and moreover that the earth spins on its axis once every 24 hours from west to east, replacing the (Geocentric) Ptolemaic/Aristotelian idea of the rotation of a sphere of fixed stars from east to west, once every 24 hours. In the Copernican (Heliocentric) universe the earth, therefore, has a speed at the equator of about 1,000 miles per hour because of its rotation.

Since the time of the Greeks, physical reality had been defined by Aristotelian Natural Philosophy together with Ptolemaic astronomy, which was seen as a workable astronomy, from which accurate predictions of heavenly events could be made. Unfortunately that accurate astronomy was not consistent with certain aspects of the reality that Aristotle's Natural Philosophy defined. It had been known for a long time that whilst equants, eccentrics, epicycles, could be used to make accurate predictions, in terms of Aristotelian Natural Philosophy they could not be physically real. It was one of Copernicus' most startling claims that his astronomy was both physically accurate and physically real.

We might be tempted to think that what Copernicus believed in 1543 is what we, as post-Copernicans believe, that we live in a world entirely defined by Copernicus or perhaps not so much by Copernicus himself but by such later astronomers as Isaac Newton. Certainly our everyday view of the universe is very close to what Isaac Newton put forward around 1700, at the end of the Scientific Revolution (following on from Copernicus). But what did Newton believe?. What does the average educated person today believe?. In general he or she would believe that the universe is infinite; that there are an infinite number of stars and therefore an infinite number of planetary systems. Certainly the educated person today does not believe that astronomers use epicycles and eccentrics, this is medieval thought. We believe that Newton and others supplied a theory of physics which can explain this infinite universe including the motion of the earth. That is all fine, but what you must appreciate is that it would certainly be mistaken for us to assume that Nicholas Copernicus believed or thought any of those things that I just defined as Newtonian or 'modern'.

Nicholas Copernicus believed in a finite universe bounded by a sphere of the fixed stars. He believed that there was only one planetary system and that we lived in it. He believed that the sun was at the centre of this finite universe. Copernicus used epicycles and eccentrics in his astronomy. He removed the equant but what he learned was that to replace an equant you have to use either two epicycles, or an eccentric and an epicycle. Therefore Copernicus' theory had more epicycles than the Ptolemaic system. **Copernicus had no new physics; no new system of physical reality to explain how the earth could move and spin.** What about the questions, how can the earth move?

What moves it? Why don't we feel it move? Copernicus could not answer any of these questions in a convincing, theoretically articulated way. He merely muttered a few Aristotelian claims about it which did not make sense. This shows up as one of the main themes running through the period after Copernicus. In the first 50 years after 1543 the numbers of his followers could be counted on two hands.

You would expect that when you look at Copernicus' system you would see some radical improvement, some clarification, of the Ptolemaic system. If you were a Whiggish historian of science, you might attribute Copernicus' insights into his superior observations of the real facts, or maybe to the fact that he had a method that no-one else had dreamed up. This idea is sometimes wrongly suggested by comparing a 'baby version' of Copernicus system (fig. 1) with a technically adequate version of Ptolemy's system, with all the epicycles, eccentrics etc. (fig. 2). But, and this may surprise you, the Copernican system also had epicycles and eccentrics -- even more than Ptolemy had -- because he had replaced Ptolemy's equants with more epicycles and eccentrics! So a technically accurate version of Copernicus' system would look more like figure 3. In order to be accurate in predictions, all the usual Ptolemaic geometrical machinery, except the equants, needed to be there. So, for example, in figure 3, the moon is on an epicycle of an epicycle and Mars is on an epicycle. And the small circle near the sun is a circulating point, and that point is actually the centre of each of the planets' deferent. Why? Because if the common center of all the deferents it were in the sun-- where we might expect it in this sun-centred system--the system wouldn't be accurate enough. As a representation of physical reality of Copernicus' system is not much of an improvement upon the Ptolemaic system. There does not appear to be much progress in Copernicus' system over the Ptolemaic.

Let's try an 'anti-whiggish' historical exercise. Let us judge which system is better, not by the standards of today; but as they might have been judged at the time. But before we do this we need to clarify something about the use of the term 'true'.

After 1543 there was debate as to which system was better or truer. A naive Whiggish way to explore this would be to ask which one actually was truer; that is, which one corresponded to the facts then known. Now the Ptolemaic and Copernican theories both consist in interconnected sets of geometric statements which are there to explain and predict the facts. And those facts are very much in the mind of the beholder as we know from previous Chapters where I have talked about Whiggish views, and theory-loading. We know the facts are shaped by prior belief so, obviously, on the one hand, we have Copernicus and his followers and, on the other, the people who follow Aristotle and Ptolemy. We have at least two sides, which have slightly different collections of facts with only limited overlap between them. Even if they all agree on the same facts, one side may say that one particular fact is very important and the other side may dispute its importance. So this notion of relating the theory to the facts is flexible and open to debate.

The bottom line in such a large struggle between two theories is that we cannot judge them straightforwardly by their respective correspondence to 'the facts'. That is the Whiggish idea. What actually happens in science, whether in the 16th or 17th century, or in the 20th century, is that there are always a number of criteria by which you judge a theory. There is not one criterion called "Is It True?". Here are some of the criteria for checking your theory: *simplicity, *accuracy, *agreement with accepted knowledge, *dramatic new predictions. It is not the criteria that are different now from 1543, but the content of the dispute, which is one of the reasons that science now is continuous with science then. You might say; "well, where does truth come into this ?". Truth is a word that we slap onto our theory if we have won; that is, if we have convinced everyone that, based on our criteria, our theory is “better”. Or if we are in the middle of the argument and I want to say my theory is better because it is good on a number of criteria my shorthand for this is to say it is ‘True’. Truth is the last word you should apply to a theory, not the first, for you can only judge on criteria like: simplicity, accuracy, agreement with accepted knowledge, dramatic new predictions. A few further points should be made here. These are not the only possible criteria. Both sides may not even agree on this, and by the way what gives us the list of criteria: facts? No, the lists are social, political, cultural upshots of previously ways of doing science...or doing anything else: your religion or your ideology might lead you to revise the list of certain criteria, or change the way in which existing criteria are assessed or weighted in debate.

Moreover, the different criteria can be given different interpretations by the two sides. What is simplicity? Is it elegance? What is a beautiful theory? Don’t you think that each side will think its own theory is very elegant, simple and beautiful? The different criteria might have different weightings or different significances. One team might say “Simplicity is the only thing.” Another side might say “Accuracy is the main criterion.” How do they know which criterion to weight more or less than other, and how to weight it? Are such decisions themselves based on 'facts'; do we have access to facts that explain how to weight criteria? No, it is based on judgements, biases, commitments, values. What about ‘agreement and consistency with accepted knowledge’: maybe the two sides have different views on what is and is not accepted knowledge. So, the whole question of criteria, their number, weighting and interpretation is up in the air; it is in play as the sides struggle and negotiate to try to find a consensus about which theory is better. (All these matters are summarised in figure 4)

So, for our non-whiggish analysis what we I need to do is build some sort of scorecard where we can score the theories. But notice, even the terms of the scorecard are up for debate. You may consider this upsetting, but it is always like that, because it is not the facts or use of the method that determine the outcome, but rather the social and institutional struggle to create and impose a scorecard for the theories in dispute. What happens when people start arguing about the score and the scorecard ? That is the whole problem of understanding science. Not how the good guys found the facts, but how the guys who called themselves the good guys made out their score to be better than the score of the other guys (After all, the good guys always win, because its the winners who write the history books!) Every dispute in the history of science is like this, and that is why they are worth studying.

Let us then look at figure 5, an attempt to develop a scorecard, using criteria and interpretations current in the 16th century. First of all, ‘accuracy’ in this particular dispute is more or less the same for both sides. (They do agree on certain things because they come from the same tradition of doing medieval astronomy). What is ‘accuracy’? In general the ‘gap’ between the predictions made by the models and the available human observational data. And the theories are both easily manipulated to bring predictions closer to existing data. To a large extent both sides agree on the data. Therefore, both sides agree (more or less) that both theories are equally accurate. So, nothing is to be gained from arguing about the accuracy of the theories.

‘Simplicity’, what does it mean? Both sides tend to agree on what ‘simplicity’ means. In 16th century astronomy it is basically the number of circles you have to use to achieve a certain degree of accuracy. The more circles the less simple; the less circles the more simple. (recall figs. 2 & 3) Both systems use essentially the same number of circles although some historians have struggled to make out some wonderful claims that Copernicus was better because he used eight or ten less circles. Neither theory is more simple in that 16th century sense of 'simple' and all the 16th century astronomers agreed what 'simple' meant. So, our scorecard stands: NIL NIL at half time. (This could be good for Copernicus, for after all he is the challenger... Or it could be good for Aristotle and Ptolemy, because they need to be actively displaced. What the score means is also in the eye of the beholder--assuming one score could be agreed upon!!)

'Agreement with accepted knowledge': this is going to be a disaster for Copernicus!. It is a disaster in one area of accepted knowledge and it is a half disaster in another area of accepted knowledge. The first accepted area of knowledge that Copernicus is in trouble with is, of course, the fundamental 'physical truth' about the universe because as far as most educated people were concerned the universe had the earth motionless at its centre, not the earth spinning and revolving out in space somewhere. There is only one way that Copernicus can win on this criterion, at least in the eyes of his own followers, and that is to apply an alternative picture of physical reality in which it will make sense that the earth is in fact be spinning and moving, and yet we humans do not observe this phenomenon in everyday experience.

Copernicus does not have such a physics and even his followers are disappointed. Some of his very eager followers like Galileo and Newton will later want to supply that physics, because it is a disaster for Copernican theory to be so physically implausible. So, according to 16th century accepted physical knowledge, **the earth does not spin or move**. What then, are we going to do: give Ptolemy a point? Or, how many points should we give Ptolemy? Well it depends who you are. It depends how you 'weight' this flaw in Copernicus' theory. If you are a Ptolemaist and you weight this as 'important' you would give Ptolemy one billion points for his being broadly consistent with Aristotle's (true) physics. If you are a Copernican and you grudgingly concede that there is a little problem (!!) then you would give one billionth of a point. Who does the scoring here? It's just like a smoke filled room in parliament, you argue and cajole, negotiate and persuade, if possible. I said the scorecard was fluid and its terms of scoring negotiable. This is a good example.

Now the other area of accepted knowledge concerns the Bible. Do not over-estimate this aspect of the debate, yet. The situation is this: in the 16th century a lot of people, but not everyone, believed that what the Bible says about the universe is the literal, real truth. So if the Bible has passages which appear to say that the sun and the moon go around the earth, then that means that this is true because the Bible says so. But, there were people amongst both the Protestants and the Catholics who took a slightly different view of the Bible and said (quite apart from the Copernican dispute) that Bible is not a physics or astronomy book and that therefore whatever it says about science is meant metaphorically or allegorically. It does not give the literal, physical truth. But most people tended to believe that the Bible contained the literal physical truth and read many passages that convinced them the earth did not move. So what do the 16th century scorers do, give a half a point to Ptolemy, or a billion points -- it depends upon where you stood.

'Dramatic new predictions': Again predictions are very much the plaything of the contending sides. If I don't like your theory, I will try to drag out of it some absurd prediction that the facts, as I see them, cannot support. If I like my own theory I will stress the predictions that it makes that are successful. Here is an example of how this works. Obviously if I had a new theory that makes a dramatic new prediction that no-one has ever made before, and if we go out and test and confirm that prediction, of course, it's going to be a very strong argument in my favour. Now lets see how this works in the Copernican case.

The Aristotelians say: "Ah, here is a new theory. It probably makes some dramatic new predictions. Well, you know how when a body rotates or spins, things tend to fly off it. (Due to what we later call centrifugal force). Well, if the earth is spinning at a 1,000 miles per hour at the equator which is faster than a horse runs, or a ship can sail, well then everything that isn't tied down should fly off the earth. The Portuguese and the Spanish have sailed around the equator where, according to Copernicus, the earth spins extremely fast in gross terms, and yet nothing was flying off. So, here is a dramatic prediction that Copernicus makes that is absolutely false. "

Here's another example: "If the earth is spinning so fast, surely the atmosphere does not keep up with the spinning earth. For instance if I move this table, I will feel a breeze in the other direction as I move it. So, therefore, we should feel a pretty strong breeze as the earth is turning. We do not feel any such breeze, therefore, Copernicus' theory is wrong."

How do we score these: minus 1; minus one million; minus one billion or even give Copernicus minus infinity, from the Ptolemaists stand point; but, for the Copernicans this is only a set of "problems to work on"!

Here's another key dramatic prediction: Copernicanism predicts something called stellar parallax. Hold your fingers up in front of your noses and blink your eyes alternately. You see the finger moving angularly against a fixed background. Hold your finger out further back and blink alternately and what do you get? Proportionately less movement. It has to do with how far your finger is away and how wide apart your eyes are. If your eyes were really wide apart even if the finger was further away you would still get a lot of movement. Now, if the earth is on an orbit, there should be observed a stellar parallax (fig. 6). Consider the earth orbiting the sun, and two points on opposite sides of the orbit -- say June and December. In June we are a long cosmic distance away from where we were six months ago in December. Clearly, if we observe the stars in June and December, at opposite ends of a long baseline (like the line between our eyes) we should observe some parallax between the stars. And indeed some parallax between the stars was observed but only in 1832, because not only do you need really big telescopes but you also need to know how to deal with the statistical errors of telescopic observation as well as some extremely complex mathematics to sort out the phenomena.

So, Copernicanism predicts stellar parallax, but in the 16th century there is no such thing as 'stellar parallax'. No-one can see it. Therefore, the conclusion that the Ptolemaics reach is that there is no stellar parallax because the earth does not move on an orbit and there is no baseline to observe from. The conclusion that the Copernicans reach is (wait for it) the sphere of the fixed stars is not as close as we thought, it is so far away that proportionately it is as though this distance is as big as when the earth was in the middle and you were just dealing with the earth's diameter. In other words, the sphere of the fixed stars is several orders of magnitude further away than anyone ever thought. This is the reason we cannot see the parallax; because it is too small to see.

This is how the debates occur in science with everybody trying to twist the weakness of the other party's theory into an advantage for their own. The Ptolemaists say,

> A major prediction is not confirmed and now you are trying to wriggle out of the whole thing by making the further absurd statement that the sphere of the fixed stars is tremendously far away. Why would God put it so far away?

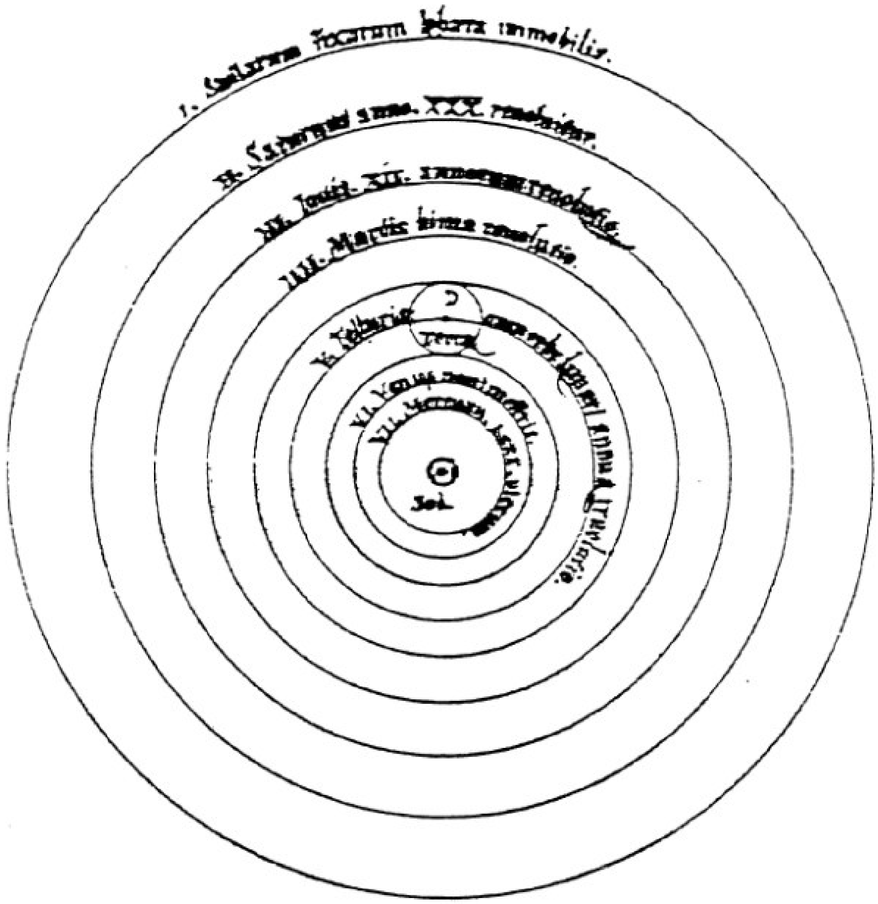
To which the Copernicans replied:

> You have not shown that our prediction is not true just because you have not yet observed it . And, we have made another dramatic prediction: the sphere of the fixed stars is surprisingly far away.

And on and on and on! Well, what is the score?, 2.5 to Ptolemy and nil Copernicus? Or, two billion to Ptolemy and nil to Copernicus. It depends on the interpretation and weighting of the criteria. But on almost any telling, Copernicus was in trouble. People were smart in the 16th century, but not many people were Copernicans.

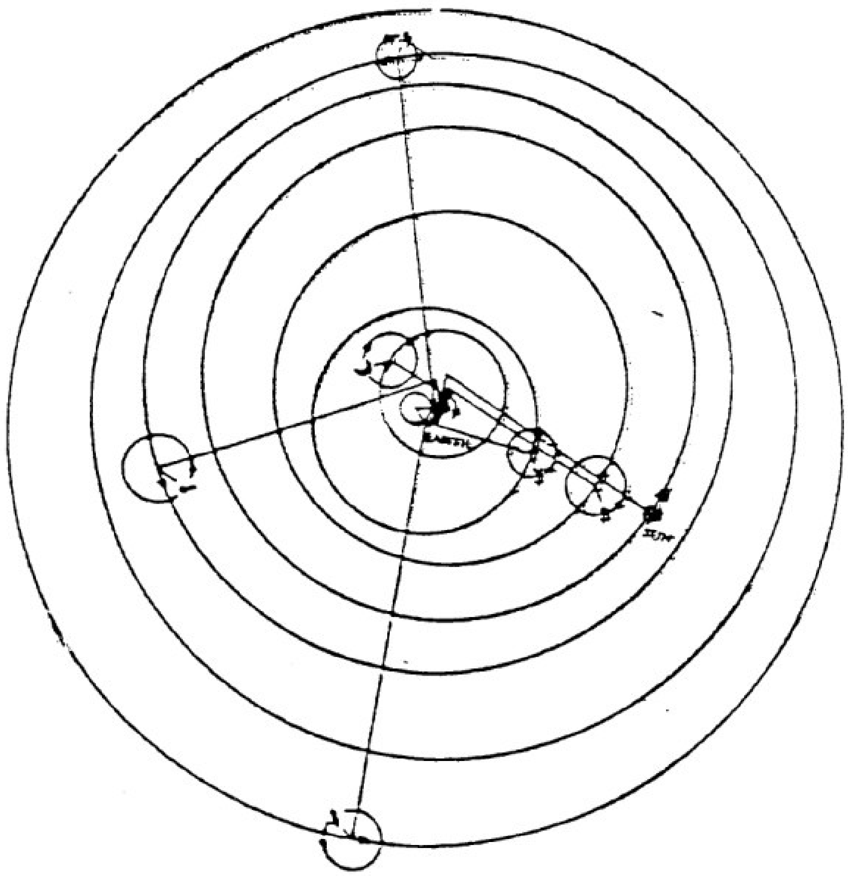
But this was not the end of the argument for one very simple reason. Copernicus had an extra criterion up his sleeve which he believed was absolutely, overwhelmingly important. He believed it overcame the short-comings of his theory in all these other areas. It is for Copernicus the one and overwhelming criterion that of course the other side does not accept as real or relevant. Copernicus' criterion states: My theory is very mathematically beautiful when you put it all together, and the Ptolemaic system is not, so my theory is true because it looks beautiful in mathematical terms. How could Copernicus make this claim, and what led him to this strange and initially unpopular position?

Figure 1



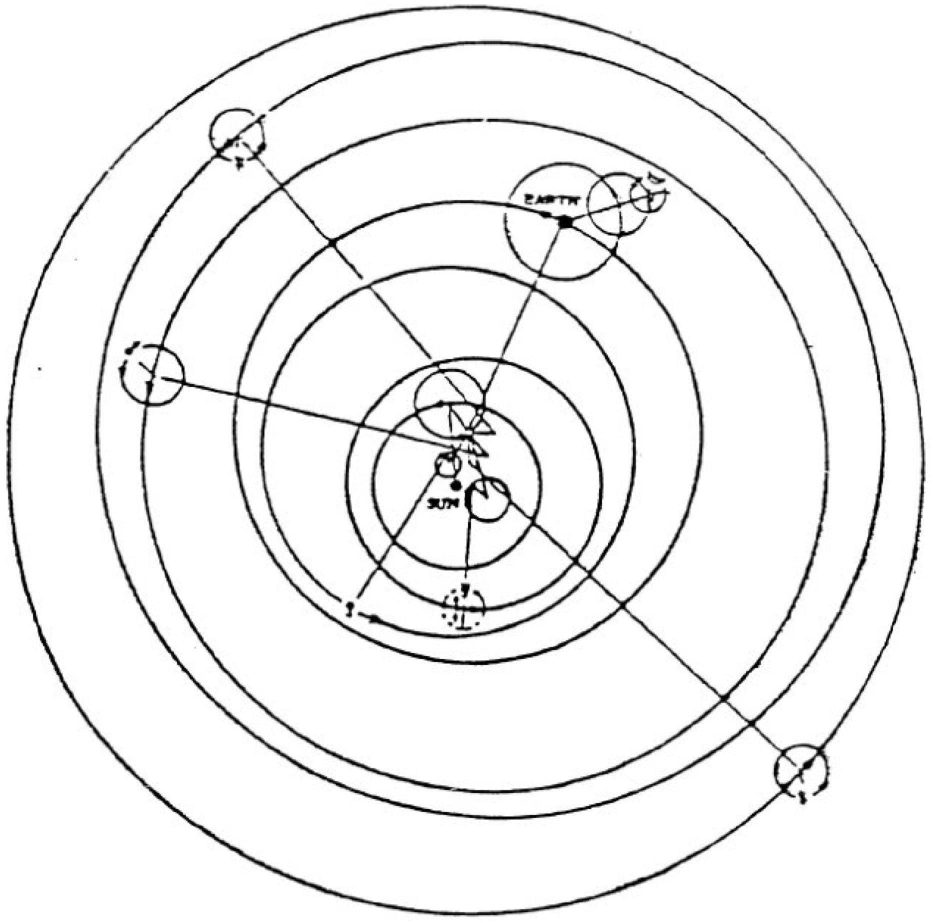
'Baby' Version of Copernical System

Figure 2



The Ptolemaic system.

FIGURE 3



New system according to Copernicus.

Figure 4

GETTING THE SCORE ON THE 'TRUTH' OF COPERNICUS' THEORY

A NAIVE VERSION OF TRUTH SAYS IT ='AGREEING WITH THE FACTS'

A THEORY IS AN INTERCONNECTED SET OF STATEMENTS INTENDED TO EXPLAIN/PREDICT SOME RANGE(S) *AND TYPE(S) OF FACT*

BUT, FACTS ARE

(1) CONSTRUCTS, SHAPED BY BELIEF, VALUES, AIMS

(2) THE RELEVANT FACTS FOR EVALUATING THE THEORY MAY THEREFORE DIFFER FOR DIFFERENT <u>CONTENDING</u> PARTIES

-THEY MAY HAVE <u>DIFFERENT</u> VERSIONS OF THE 'SAME' FACTS
-THEY MAY HAVE DIFFERENT (ONLY PARTIALLY OVERLAPPING) SETS OF <u>FACTS</u>
-THEY MAY WEIGH DIFFERENTLY THE IMPORTANCE OF EVEN THOSE FACTS THEY AGREE ON

S0, A THEORY AS SUCH DOES NOT CONFRONT THE GIVEN OBJECTIVE 'FACTS'. A THEOR Y IS NOT OBVIOUSLY AND DIRECTLY 'TR UE' OR 'FALSE'.

THEORIES ARE WEIGHED UP, JUDGED ACCORDING TO CRITERIA OF PERFORMANCE, SUCH AS

l. SIMPLICITY/ELEGANCE OF STRUCTURE

2.ACCURACY IN EXPLAINING/PREDICTING THE 'RELEVANT SET OF FACTS

3. CONSISTENCY WITH ESTABLISHED BODIES OF KNOWLEDGE

4. MAKING 'MAJOR' NEW PREDICTIONS THAT AGREE WITH THE 'RELEVANT' FACTS.

AREAS OF FLEXIBILITY & INTERPRETABILITY IN USING THESE CRITERIA:

A. 1 TO 4 MAY NOT BE THE ONLY CRITERIA JUDGED RELEVANT BY DIFFERENT GROUPS.

B. 1 TO 4 MAY EACH B E GIVEN DINERENT INTERPRETATIONS BY DIFFERENT GROUPS

C. 1 TO 4 MAY BE GIVEN DIFERENT WEIGHTINGS BY DIFFERENT GROUPS

D. THE 'RELEVANT FACTS MAY BE DIFFERENT FOR DIFFERENT GROUPS, AS NOTED ABOVE.

E. THE 'ESTABLISHED BODIES OF KNOWLEDGE' MAY BE DIFFERENT FOR DIFFERENT GROUPS

TRUE' IS THE LABEL EACH SIDE APPLIES TO THE THEORY IT 'SCORES' HIGHEST, USING THESE NEGOTIABLE CRITERIA IN RELATION TO THEIR OWN PREFERRED SET AND INTEPRETATION OF THE FACTS'.

Figure 5

Scoring Ptolemy & Copernicus

Criteria	Ptolemy	Copernicus
Simplicity	even	even
Accuracy	even	even
Agreement with known facts	+++	0
dramatic predictions confirmed	n/a	failure(s)?