FRIENDS OF THE LIBRARY WINTER LUNCHEON
Dedication of the Special Collections Room
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Speaker: Dr. Owen Gingerich
Professor of Astronomy and History of Science,
Harvard University, & Astrophysicist, Smithsonian
Astrophysical Observatory

When I saw that this room was going to be dedicated at precisely the point that my wife and I were planning to be in Southern California, there was almost nothing to keep us away. We were keen to come and help share with you the opening of the Special Collection.

It has a special place in my own research because, as a historian of astronomy, I find that the Zinner Collection contains some very interesting and even unique materials in it. I met Ernst Zinner only once. He was an old man, and although I'm sure he commanded English quite well for his research purposes, he didn't actually speak it. So, I can't say, since my German was even worse than his English, that we had much communication. But, it was interesting to meet him back in 1965 before he died. Since then, his collection has become the basis of the early science part of the Special Collections.

I'm going to talk to you this morning about a question that Zinner would have been much interested in. I've taken as my title "Circles of the Gods: Copernicus, Kepler and the Ellipse." The first part of it comes from a recent book by a Louisville

Seminary professor, his name is Harold Neblesek(?). In his book, called Circles of the Gods, he says that the perfection of the circle was a theological idea that came from the ancient Greeks which held Astronomy in thrall for many centuries, and only with the breaking of this belief by Kepler could Science free itself from such constraints and could begin to make real progress.

I'm rather critical of this notion because it seems to me that the circle is exactly the place to begin if you wish to represent celestial motions. The notion that the heavens were eternal and that a circle which goes round and round forever was the pattern to use to represent the heavens was not a bad one. In fact, you can represent the heavens pretty much as closely as you want if you use the proper combination of circles. So, it seemed to me that the idea of using a circle as a starting point to represent celestial motions was really a rather good one and I thought Neblesek's arguments against this were really badly misplaced. I wrote a critical review of the book and then forgot about it.

Recently I was given a manuscript to read from what will no doubt be a very widely selling, popular book on astronomy that will cover the scope of it from antiquity to modern times. According to this account, Copernicus made a mighty leap forward when he turned away from a geocentric universe to a heliocentric universe, but was shackled by his failure to find the ellipse.

Hence, his astronomy was fundamentally flawed. The same argument which Neblesek had used with respect to Copernicus. This all upset me enough that I decided to address myself to this topic because I think that's all nonsense.

Both Ptolemy and Copernicus could get just as much accuracy from their model with circles as was needed for the particular accuracy of observations that were available to them. It was not until Tycho Brahe that one got observations that were sufficiently precise that one could, in fact, just barely tell the difference between a circle and an ellipse for the motion of the planets. Within ten years of the time when those accurate observations became available, Kepler had in fact found and announced the elliptical orbits of the planets. So, I cannot see that in any way Copernicus was a failure for not finding something that he could not possibly have found because he simply did not have the observations available.

Now, that's it folks! That's my whole speech! Now I will proceed to embroider on it. So, if we can turn on the slide projector and turn off the lights, I will show you a little bit more about what I have in mind here.

I begin with Johannes Kepler, who is in some ways the hero of our particular talk today. One of the reasons is to show you one of the known images of Kepler. I'm reminded of all this imagery of Kepler because recently a company printed an advertisement that had a picture of Kepler, which was obviously not Kepler. Out there in the great reading public somebody noticed this and got sufficiently annoyed to write the company a nasty letter. They turned it over to their advertising agency, which happens to be located here in San Diego, and they said that they got it from a really good archives. I was interested. I don't know if they got it from the Zinner Collection or not, but that would've been a good starting point.

But, back in 1932, Zinner wrote an article about the images of Kepler and in it he showed the one that was used in the advertisement. He explained that although this had been identified as Kepler, this was entirely false. It was actually Maximillian the Tenth of Bavaria. The advertising company turned to me to find out what they had done wrong and I had to research this to find out how many honest images of Kepler we've got. Well, I guess I'll say we have four and a half, and this is the half. This was found in a castle in Czechoslavakia around the time of the 400th anniversary of Kepler's birth in 1971. It looks enough like the other pictures of him and the date of the portrait is about right, so I think that it might very well be Kepler. But, it's not 100 percent authenticated. So much for Kepler.

Here's what he did. This shows you the ellipse. The ellipse is basically an off-centered circle. Now, you say it isn't that because it's all squashed in. But, for all of the planets, the difference between the off-centered circle and the ellipse was about the size of a pencil line if you're drawing on an ordinary sheet of paper. Unless you have a great deal of eccentricity on the ellipse, it doesn't begin to go in.

What is absolutley crucial, however, is the second law that Kepler discovered which is the law of areas. This tells us that the planet, as it goes around in its ellipse, sweeps out equal areas in equal times. So, when it is far from the sun, it doesn't need to move so far to make a triangle of the same area that it does when it is close to the sun.

In modern physics we know that this is an accurate representation of what we call the law of conservation of angular momentum, which has many practical applications, among others being championship skating. Here you see the skater with his arms and leg out to get the maximum amount of this angular momentum even though he's turning only very little. But, when he pulls his arms in, he then speeds up a great deal because of this conservation law, the conservation of angular momentum. Unfortunately, my flash was so fast that it caught him still, he should of course be a blurr as he's spinning around. One thing that you can see is the way that his hair spins out, almost like a little halo. He is actually in a very rapid spin at this particular point.

You cannot get to first base when talking about planets unless you do something in your model that will account for the conservation of angular momentum. Now, that's anachronistic. That's a modern term. Ptolemy, who is seen here as he appears in the church at Ulm in Germany, did not know about angular momentum. He would have been baffled if you had used that word.

But, he knew that he had to do something when he was modeling the planets because they went sometimes faster and sometimes slower. Now, I'll show you how he did it.

Here is a manuscript. This was formerly in the Honeyman Collection up at San Juan Capistrano. Long ago before that, the manuscript belonged to Michael Maestlin, who happened to be the teacher of Johannes Kepler. This is the representation of how Ptolemy made the planets move. Sometimes the planets go backwards in the sky--the so-called retrograde motion. We needn't worry about that very much, but let me just say that Ptolemy did it by having a second circle here [pointing to slide] which was this epicycle that would cause the planet to come in, swing around in the loop, and go backwards before it began to go forward.

But, the part which I want to talk about, the unequal motion, Ptolemy did in a different way by what he called the equant. Here you have the Earth [pointing to slide] off-center and you see right away that this is a kind of approximation to the ellipse because he's putting the Earth off-center, not the sun, but it converts out to be very much the same thing. Here's the center of the circle, the so-called deferent or carrying circle. The deferent carries the epicycle around, but here [pointing to slide] is the seat of uniform motion. So, if this is a planet with a period of about four years, it will move through ninety degrees in one year, it will move the next ninety degrees another year, and so on around. But, because the equant is placed up here [pointing], it means that the epicycle moves slowly here and in the next ninety degrees it has so much farther to go, it's going to move faster and faster. So it moves rapidly here and slowly up at this end [pointing].

Ptolemy, without actually knowing what he was doing, was making a very good approximation for the conservation of angular momentum. But all he was doing was trying to do was to represent the planets as he observed them. He knew that they were going faster at the one side than the other and that's how he did it. It was remarkably accurate. He didn't have such perfect observations. You must understand that occasionally he got them to within ten minutes of arc. That would be about one third the size of the moon in the sky. But, often his observations were even less accurate than the diameter of the moon. He didn't have very good material to work with, his instruments were not so great and, of course, he had no telescopic sights.

We turn now to a figure from Spain in the Middle Ages in the thirteenth century. This is Alfonso the Tenth, Alfonso the Wise. This is a very official representation of him because this is the medalion in the U.S. House of Representatives where great law givers are represented up around the balistrade of the balcony. Here is King Alfonso and he was a great patron of the arts and the sciences. He sponsored a series of tables and other astronomical treatises and here's an example of a section of the Alfonsine Tables. This is a manuscript copy of it. If you look at these tables very carefully, you will see that they are closely based on the earlier work of Claudius Ptolemy, who worked in the second century A.D.

There's a very famous anecdote about Alfonso that he was said to have told his astronomers that had he been around at Creation, he could have given the good Lord some hints! The implication being that it was so complicated with all those circles, he certainly would have made things a little bit simpler. This has given rise to the notion that somehow the astronomers of the Middle Ages, observing faithfully and getting it more and more accurate, had been unable to settle just for that big epicycle (which you saw) that Ptolemy had; and they then had little epicycles riding on the big one and so on down the line.

I think that this is a notion that came in during the last century when a French mathematician named Fourier showed that you could represent a mathematical graph as exactly as was wanted by a whole long trigonometric series. Where adding another trigonometric term to the approximation made it increasingly accurate--which would be like adding another circle to the circular approximation of the heavenly motions. This is entirely ficticious because as it turns out, there was very little observing going on during the Middle Ages and that there were simply no mathematicians clever enough to figure out how you would have been able to add another epicycle to the existing one. Ptolemy had used such beautiful mathematical tricks based on the idea that there was just a single epicycle, this would have bothched up the whole structure of the system. It just wouldn't have worked.

I have made a computer analysis of these Alfonsine tables and it's perfectly plain that they are very simple and pure Ptolemy. Here is an ephemeris which was published while Copernicus was a youngster. It's an incunabulum of the ephemerides of Regiomontanus. Again, I have duplicated these with the computer and shown that they are, in turn, pure Alfonsine--based on the simple Alfonsine Tables.

So at the time of Copernicus one had still essentially the basic, simple astronomy of Ptolemy in hand. Yet, the rumor has come that Copernicus had made a vast simplification.

I suppose in part it stems from this little tract that Copernicus wrote [the Commentariolus]. He handed it around to some friends. We have no original copy, but this is one of the copies made in the sixteenth century of it. It ends by saying, "Behold the entire ballet of the planets can be accomplished with only thirty four circles." I fixed my camera to its sharpest right there on the "thirty four" [slide]. Somehow, this was understood as saying that Ptolemy had so many circles and I, Copernicus, have managed to get it down to only thirty four.

In reality, Copernicus was using more circles than Ptolemy. What he was so excited about was just simply that the motions in the heavens appeared to be so complicated and yet, with only thirty four circles he could make a very fine representation of it. Copernicus said that if he could represent all of the planets within ten minutes of arc, which is to say one third the diameter of the moon, he would be as happy as could be. That was approximately the accuracy of his best observations. But, many of them were much poorer and for the most part he used Ptolemy's observations.

He believed that this was a great heritage from antiquity and he could not dare doubt that those were precise and good observations. So his astronomy was essentially not that much better in terms of accuracy than Ptolemy's. Nevertheless, it had... let me just go to the next slide... a very important effect of simplification.

Ptolemy had to use two circles to represent Mars, the big deferent circle and the epicycle. Well, so did Copernicus. He had to use the orbit of the Earth and the orbit of Mars. But when he turned to Venus, which Ptolemy required two circles to do, Copernicus had to use two circles but one of them was the same--the orbit of Venus and the orbit of the Earth. He was able to use the orbit of the Earth over and over again which essentially connected together all of the disparate, separate mechanisms that Ptolemy had for each individual planet. The great accomplishment of Copernicus was getting it all linked together.

Now let me back up, since this is a meeting in the celebration of books. I thought I should show you Copernicus' library. In showing this slide I think I really ought to pay homage to two figures of southern California who have had a very stong influence on my own life and work and who are no longer with us: one was Charles Eames, the designer in southern California; it was with him that I took this picture. He had gone with me to Upsula in order to work for a great exhibition about Copernicus which has been subsequently used by IBM and has occassionally been shown since then. The other person I think of is of course someone who was very instrumental in helping the collection here, Jake Zeitlin. It was Jake who was always so extremely generous in giving me information about where to find particular books in collections and in obscure places. Sneaking me in to places in wonderful ways and so on. He was also very helpful and very influential. In showing this slide of Copernicus' library, I think of both of those people; a bookman and somebody who taught me a great deal about photography and how to view things.

Now I want to go on. Here is the man I spoke of before in a rather youthful portrait with his bright eyes and mustache--Tycho Brahe. The man who decided to reform astronomy. That's when as a teenager he made an observation of a great conjunction of Jupiter and Saturn and saw that the very best of tables based on Copernicus were wrong by over a day. Those based on the Alfonsine Tables were even worse, so he decided that he would devote his life to getting measurements so that Astronomy could be reformed.

It was with giant instruments, such as this mural quadrant, that Tycho was able, finally, to get the observations of sufficient precision to tell the difference between a circle and an ellipse. Tycho says that this instrument was basically just a wall with a vent up there in the top [pointing to slide] where the light of the stars could come in and very, very large, stable measuring quadrant. He says that he doesn't want to waste the space in his book, so he shows a painting on the wall with himself, his alchemical laboratory, his library, his students, the assistants out making the observations, and all of that. In fact, we can see a typical view of the students making the observations--here with a sextant and with a quadrant. With these wonderful kinds of instruments, he was able to get a set of observations the likes of which the world had not seen before.

Here is, indeed, one of the books of observations which were to become paramount to a young astronomer who came to visit him eventually. [New slide] This is one of those authentic images of Johannes Kepler, almost a baby-faced young man; but this is very much how he looked at the time he came to work for Tycho Brahe. The little miniature of Kepler and his new wife on a matching one is now in Leningrad.

He had been a high school teacher in Prague in southern Austria and, while teaching his class one day, a sparkling notion came to him about why there are six planets in the Copernican system. He had gone to Vienna and studied with Michael Maestlin and come away a convinced Copernican. If he had been a Ptolemaist, he would have counted the Sun and Moon as well as Mercury, Venus, Jupiter, Mars, and Saturn as seven planets. As a

Copernican he had only Mercury, Venus, Jupiter, Earth, Mars, and Saturn. He had six planets and there are five Platonic solids; regular solids like a cube, a tetrahedron and so on.

What he discovered, for example, was that if he had a sphere here for Mars and he put a dodecahedron inside with its vertices just touching it and then the faces touching the next sphere in from there, it just fit. The tetrahedron is on the other side of Mars. Inside the Earth you have an icosahedron which separates the Earth from Venus and inside, if you cheat a little bit, you get an octahedron just nesting in there to separate Venus and Mercury. It was all wonderful and it didn't quite work, but just well enough to convince him that it was something great. It worked within ten percent. He made a book about it and sent copies off to various people including Tycho Brahe up in Denmark.

Tycho saw that here was somebody who had a great imagination, a great ability to work with mathematical figures, including in three dimensions, so he promptly invited Kepler up to work with him. Kepler said that this was way too far; there was no possibility of going up. But he said that it was part of Divine Providence that Tycho would leave from Denmark and come down to Prague. He didn't say that it was also Divine Providence that the Counter Reformation swept in and all the Protestant teachers were given until sundown to leave, but that was also part of what happened to Kepler. So he was moved up to Prague without a job and Tycho took him in as a subordinate.

Kepler wasn't quite prepared for that because he thought he was a pretty good astronomer and should be considered part of the regular staff, not that low down. Tycho was extremely secretive, but would occassionally hand out some observations. Here in Kepler's notebook [slide] he has got one of the precious observations from Tycho. So precious, in fact, that he put this double line around it so that he could always get back and find it again.

What Kepler did was an ingenious plan to try and work out the orbit of Mars because at that time Tycho and his assistants were very much worried about Mars. Mars is the planet that comes closest... no, it isn't, it doesn't come quite as close as Venus does, but close enough to get a complete set of observations. Also, it has a pretty eccentric orbit. You can see that by the way in which you have a circular orbit here [pointing] for the Earth and circular orbit for Mars which is considerably off-centered. That is the eccentricity of the Martian orbit. Kepler again said that it was Divine Providence that Tycho was at work on Mars because it was only from Mars that you could get the secrets of the Heavens.

Here you can see how he is going to tease out this information. Mars goes around more slowly than the Earth and he knew that if the Earth was here [pointing] and he was observing Mars, that as the Earth goes around here and gets back to the same point again, Mars will have gotten over here [pointing] some place. After 687 days Mars will get back to the same place where it was, and the Earth will have gone not quite around a second time and will have gotten over to here. So, if you happen to have an observation that was made exactly 687 days later, you know Mars was in the same place and you can get a triangulation.

This was a very lucky situation because he was able, from Tycho's observations, to get out five of those observations of Mars at successive intervals with the Earth here, here, here, here and here [pointing]. In triangulating from Mars, what he found and what you can see in his book is that Mars didn't travel in a perfect circle because the triangulation showed that Mars was inside the circle. This was the first time that there was a sufficient base of observations to see that maybe a perfect circle wasn't what was going to be required.

But, what was required? In the standard mythology it says that Kepler just got all of these wonderful observations from Tycho, went merrily triangulating around, found all of the points, and then fit a curve through them. Alas, life was not that simple! The observations of Tycho were good, but not that good. There were errors in them and so there is a continual scatter where it was falling. Kepler said eventually that it was a method of votes and balance. You couldn't just fit the curve through, you had to see sort of which way it was going.

Now I want to come back to what it was that Kepler could do in order to get to the ellipse. But at this point we have a digression. Since you're a bookish crowd, I thought I would tell you a little something about chasing after rare books because, surprisingly, this comes back around to give some interesting insight to what it was that Kepler was up to. I think many of you know, because I have spoken to the Friends before, about my search after copies of Copernicus' book, the de Revolutionibus which was published in 1543, the second edition in 1566.

Here I come to a collector in Connecticutt with my collegue, Urshi Gogisky(?) from Warsaw. There is Harrison Horblit who owned this fabulous copy of Copernicus' book (first edition) and we're having a look at it. What Gogisky noticed right away was that, here where there is a Greek poem written in the flyleaf, that this was exactly the same text, only in Greek, that appeared in Kepler's copy of the book. The only thing is, in this particular copy, is that it is signed at the bottom, Joachim Camerarius with an Iota and a Kappa. Camerarius was a professor of languages at Leipzig. In addition to teaching there, I suppose he was the man to get to write a Greek poem in the front of your book. He was publishing these Greek dedicatory poems in one book after another.

I suspect that young Rheticus, the man who got the manuscript [of de Revolutionibus] from Copernicus and had brought it to Nürnburg to publish, asked Camerarius to write a nice Greek poem to go at the front of Copernicus' book. I suspect that this is the poem he wrote. It's a wonderful poem; a Platonic-type dialogue between a philosopher and a stranger. The stranger says, "What is this new book I see?" and the philosopher says, "Well, it's a new one," and the stranger says, "Is there anything good in it?" and the philosopher says, "Take a look and see!" It ends up by saying, "Don't be like the unlearned and just dismiss this out of hand and, if you are critical of it, see if you can do any better."

Rheticus left Nürnburg, where the book was being published, and went down to Leipzig to take up a teaching position and the publication of the book, including the front matter, fell into other hands and the Greek poem was never included in the book. So, Rheticus asked Camerarius to write his poem in the book anyway and this is the copy that Rheticus sent back to the Dean at the University Wittenberg.

What Gogisky recognized was that the poem matched the one that is in Kepler's own copy. Here is Kepler's copy of the book and as you can see, just faintly over here on the side [pointing], the poem in Latin and it's signed I. K., which everyone supposed stood for Johannes Kepler. But, not quite! It says "vertit", which means: translated. This is one of those wonderful kinds of puns that Kepler always liked. It stands not only for Johannes Kepler, but it's also the iota/kappa for Joachim Camerarius, the man who had written the original in Greek.

In the course of trying to find every possible copy of Copernicus' book, I went to the library in Parma and they couldn't find their first edition. They even showed me the hole on the shelf where it should've been! I figured that somebody had it out and was just using it in some office or someplace. So, I mentioned it to my colleague, Robert Westman, who's here in

San Diego and is moving now to teach in La Jolla, and he said, "That's funny, it was also missing a year ago when I asked for it." So, I wrote to them and asked them to send me a xerox of the entry in the catalogue if it was still missing.

They sent me the entry in the handwritten catalog which I had vaguely remembered. It said, "This is a copy with a Greek poem written in the front of it written by Joachim Camerarius." I thought, AHA! This copy that Harrison Horblit had mysteriously appeared on the market just after World War II and I thought that this was the perfect description of the book. The book was auctioned for a princely some, at that time at least; it was one hundred thousand dollars for that copy. Subsequently it was advertised for one hundred and fifty thousand. It was eventually bought by another book collector and I asked him to bring it by sometime.

He did. He brought it to my office and we went down to this closet down the hall which is absolutely pitch black. I got out my ultra violet light and we put it all over because this is an interesting way to bring up any ink that has been erased, or any traces of shelf markings and so on. The book was absolutely clean; not a shread of evidence that it had ever been in the Parma library. It seemed to me that the evidence was inescapable.

The reason that I'm telling you this story on myself is just to show you how dangerous it is to jump to conclusions, because a couple of years ago, a book dealer in Paris told me that he was on the trail of an extremely interesting copy of Copernicus' book because of the material that was written in it. When I went to see him, he showed me xeroxes and to my great surprise, it was exactly that Greek poem, in the same hand as Camerarius and signed by Camerarius. It was a different copy because the break in the lines between one page and another was different.

I told him about the Parma library and he said, "Hmmmmmm...., this book has a problem. I received this mysterious phone call from somebody asking me if I was interested in this collection of books in a private collection in Italy. I said fine and they said they would get in touch with me later." The next thing that happened was that this big pack of xeroxes came in the mail with no return address and nobody had ever contacted him again. So, we know the book exists, but we haven't got a clue to where it is other than it is in some private collection in Italy. It seems to me, that if you're going to have to pick which was the copy stolen from the Parma library, well, it probably not the one in the hands of Haven O. Moore(?).

In looking closer into this copy of the book, owned once by Kepler, there are some very interesting manuscript notes in it. One would assume that this was in fact put in by Kepler. Not quite, because the handwriting here is not Kepler's, it's somebody else's noticing this. There's another handwriting patch in a different hand and interestingly, that hand turns out to be Michael Maestlin's. So, Kepler took the book around to his teacher and his teacher wrote this little note in it when they were looking at the book.

This passage in particular says that there is some question as to whether the center of the universe is the center of the Earth's orbit or the Sun itself. {All astronomers up through Copernicus basically used the center of the Earth's orbit as the reference point for the solar system.} The first thing that Kepler did when he came to work for Tycho was to say, "Can I use the Sun itself as the reference point because I think that this is physically more important as the Sun must be the driving force that makes the planets go around. Therefore one should use, not this empty space, which is the center of the Earth's orbit, but one should use the Sun." This turned out to be a crucial first step that Kepler took.

It's interesting that, in the copy of the book that he happened to get, it is exactly the part that is highlighted. Even more so, there is a place where Copernicus is describing his particular mechanism which doesn't, with the combination of circles, yield quite a true circle as the result. In fact, what it yields is, and this is written in Greek, an ellipse. Now, again one would suppose that this was Kepler's note and so on, except, in searching for so many copies of Copernicus' book, I've discovered that this is a family of notations which exists in five copies. They were all put in the book early on before Kepler was born. So, it was by chance that the copy of Copernicus' book that Kepler obtained was one which had a few prior annotations put in it at the critical points where Kepler's own astronomy would take its point of departure. I think that this is a fantastic fact and it must be telling us something about the psychology of discovery. Otherwise, I don't know what to do with it and I simply show it to you as something fantastic.

Let's go back to the previous line of thought. Here is what Kepler was doing: he knows that he doesn't have a circular orbit, but how can he come to a final representation for the circulation of Mars. Kepler believes that the Sun is, in some way, providing the driving force that keeps the planets going around. But, that doesn't tell him why they are moving sometimes close to the Sun and sometimes far from the Sun. He knows that there is one thing that can sort of reach across empty space and have its influence--magnetism. So, if you want the Sun somehow driving the planets around and yet there aren't any linkages between the Sun and the planets, maybe it's an invisible lingkage of magnetism.

When you've got magnetism and magnets, you have things like a compass that have a North and a South pole. Perhaps this is the magnetic axis of the planet [pointing] and as it comes up like this, there's a repulsion driving it away from the Sun's magnetism with the effect of to push it farther away and then it's in a neutral position again. Then the head comes in again and there's an attraction to the Sun, so that when it moves here [pointing] it's pulled back in. Can it be that the magnetism can do this?

When you work out the projection like this from an axis, the simplest curve that you get in the first approximation turns out to be an ellipse. That's why Kepler chooses an ellipse as a possibility to fit through these points that he's got from the triangulation. It's sort of uncanny that he stumbles across the right curve for mostly the wrong reasons, but he gets it.

What's going on here? [pointing] It looks sort of like a whiskey bottle exploding or something, but actually that's a rudder. The rudder of the planet guiding itself around in this magnetic affluens. Here, in fact, you can see the boatman with the boat and Kepler says that it's sort of like a boat in an amusement park which goes back and forth because of the current. Today in Basil there's exactly such a boat going across the Rhine. Here's the cable [pointing] which stretches across the Rhine; here's the pulley which is then connected down to the boat. The boat itself has no power, it's the boatman who sets the rudder so that the flow of the Rhine drives the boat one way across and then he changes it to the other setting and the boat comes back again being constrained by the pulley. That's how Kepler worked it out as the rudder of the planet that drives it close and then far from the Sun.

Here it is all done with all the geometry for how the magnetism works out [pointing]. An ellipse it is and here is the girl on the chariot with the laurel wreath riding up to crown him for thinking up such a neat idea! Here, indeed, is the ellipse as it was taken over by Isaac Newton. One of these manuscripts turns out to be absolutley key to the idea of universal gravitation and the way in which gravitation works with an inverse square law. Of course, in Newton's hands there evolved an apparatus for coming out with the idea of conservation of angular momentum--the moment of the quantity of motion as Newton called it.

To go to Newton would be to take us too far beyond the present line of argument. I only wanted to get you to Kepler and once more to say that, when the observations of sufficient accuracy were finally available, the ellipse came very, very quickly. The lack of an ellipse with Copernicus or Ptolemy was not an issue of contention because they simply couldn't have gotten to an ellipse. They didn't have these observations of one and two minutes of arc accuracy which were essentially needed in order to get there.

That's my story, the story of the Circles of the Gods, which I think weren't all that bad for their own time and occassion. Thank You.