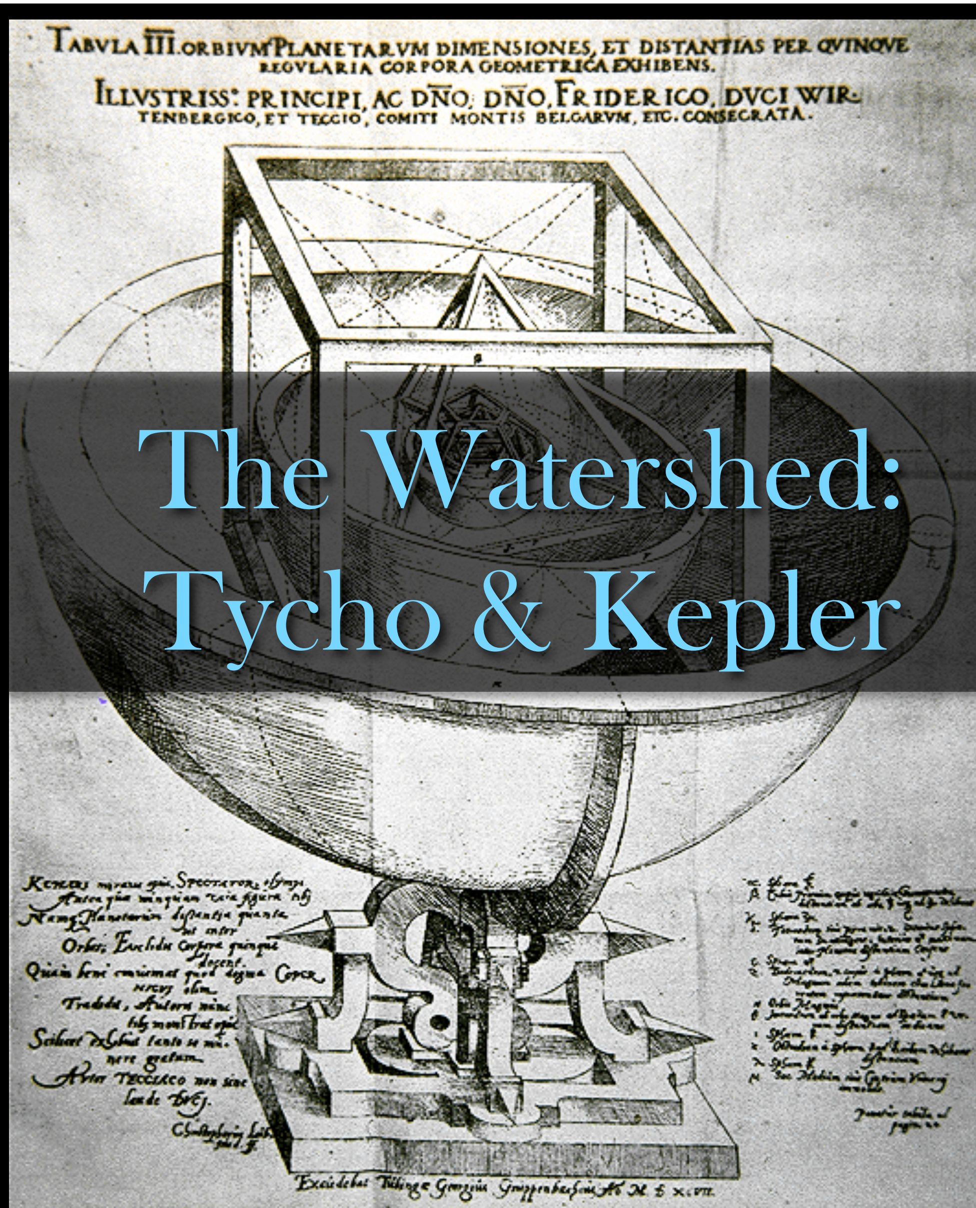
The Watershed: Tycho & Kepler



Prof. David Kaiser

Wednesday, November 10, 2010, STS.003

Heavens unit

Overarching questions:

Are representations of astronomical phenomena *true* or merely *useful*?

How does scientific knowledge travel?

I. Tycho Brahe: Noble Observer

II. Johannes Kepler: Mystical Physics

III. The Watershed

Readings: Copernicus, *On the Revolutions of the Heavens*;
Kepler, *Mysterium Cosmographicum*;
Lerner and Verdet, "Copernicus."

The Watershed

Images of "The Watershed: A Biography of Johannes Kepler" and "The Sleepwalkers: A History of Man's Changing Vision of the Universe," Arthur Koestler, removed due to copyright restrictions.

Noble Observer

Tycho Brahe (1546 – 1601) was born into the Danish nobility, with close ties to the King of Denmark.

His uncle abducted him as a young child – arguing that his father already had enough sons – and so Tycho's upbringing differed from that of his brothers. He went to university; they pursued traditional military careers.

Tycho Brahe, ca. 1586

He still fought battles – e.g., a duel as a university student (with one of his cousins), in which he lost his nose. While recuperating, he studied medicine, astrology, and alchemy.

Uraniborg

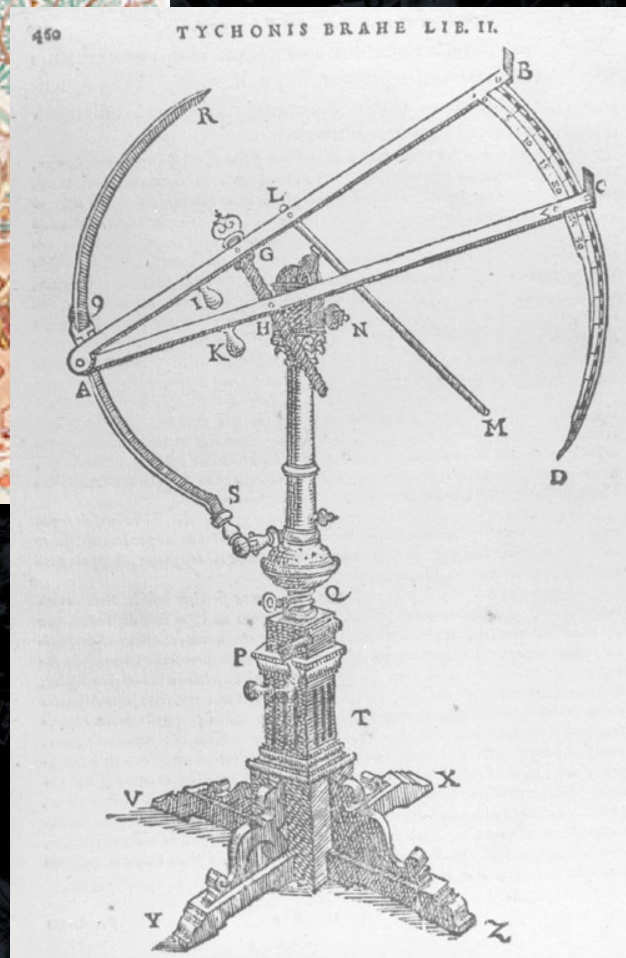
printing press and paper mill;
alchemical lab;
observing stations;
huge library

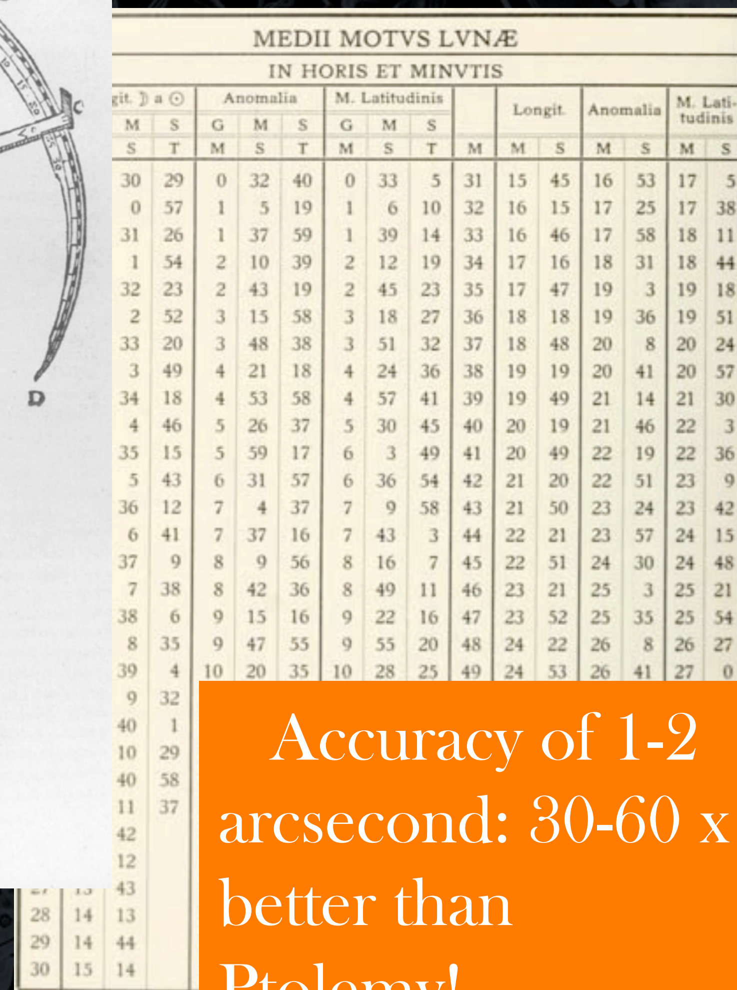
Uraniborg castle, ca. 1576

Island of Hven

A gift from the King:
Renaissance patronage

Labor, Instruments, & Observations





MEDII MOTVS LVNÆ

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0	57	1	5	19	1	6	10	32	16	15	17	25	17	38
31	26	1	37	59	1	39	14	33	16	46	17	58	18	11
1	54	2	10	39	2	12	19	34	17	16	18	31	18	44
32	23	2	43	19	2	45	23	35	17	47	19	3	19	18
2	52	3	15	58	3	18	27	36	18	18	19	36	19	51
33	20	3	48	38	3	51	32	37	18	48	20	8	20	24
3	49	4	21	18	4	24	36	38	19	19	20	41	20	57
34	18	4	53	58	4	57	41	39	19	49	21	14	21	30
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35	15	5	59	17	6	3	49	41	20	49	22	19	22	36
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36	12	7	4	37	7	9	58	43	21	50	23	24	23	42
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37	9	8	9	56	8	16	7	45	22	51	24	30	24	48
7	38	8	42	36	8	49	11	46	23	21	25	3	25	21
38	6	9	15	16	9	22	16	47	23	52	25	35	25	54
8	35	9	47	55	9	55	20	48	24	22	26	8	26	27
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10	29													
40	58													
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42														
12														
43														

28	14	13
29	14	44
30	15	14

Competing observation teams, standardized log books, tracking of systematic errors

Accuracy of 1-2 arcsecond: 30-60 x better than Ptolemy!

Nova Stella

In 1572, Tycho observed a bright new star, or *nova*. Although Chinese astronomers had recorded novae for millennia, this was the first recorded in Europe.

Images of "Science and Civilization in China," Joseph Needham, and Supernova SN1572: B Cassiopeiae removed due to copyright restrictions.

Chinese cosmology had long emphasized flow and change in the heavens, unlike Aristotelian cosmology.

Where's That Star?

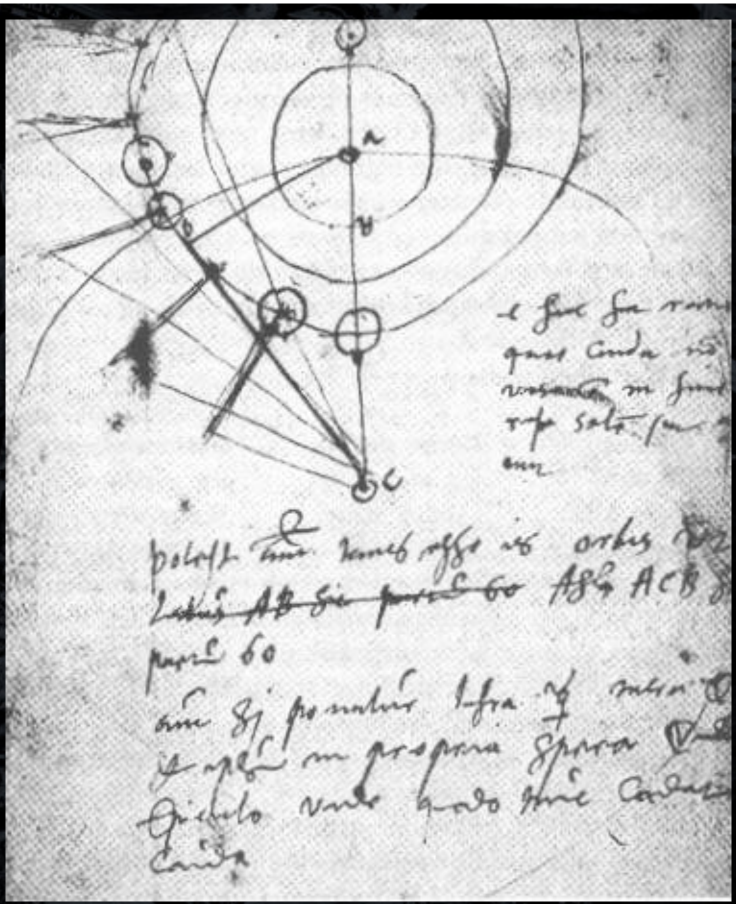
Thanks to the 'republic of letters,' Tycho could compare notes on the nova's apparent position with observers throughout Europe.

Tycho Brahe, *De Nova Stella*, 1573

From the lack of observable parallax, Tycho concluded that the nova must be in the superlunary realm — and hence there *could* be change there, contra Aristotle.

Crystalline Spheres?

Tycho tracked the comet of 1577 for weeks. Based on his observations and his correspondence with others, he again concluded that the comet must be superlunary (rather than an atmospheric disturbance).



Tycho's notes on the 1577 comet

Moreover, as Tycho continued to analyze his data over the next decade, he realized that the comet's path cut straight through several planets' orbits. Not only was change possible in the heavens; perhaps there *were no* crystalline spheres of Aristotelian "quintessence."

Copernican Convert

Tycho was among the first to teach Copernican astronomy: 1574 at the University of Copenhagen. He was impressed with Copernicus's work, but also troubled by it.

He was also among the first to critique heliocentrism from a religious point of view.

Jean Fouquet, *The Battle of Jericho*, ca. 1475

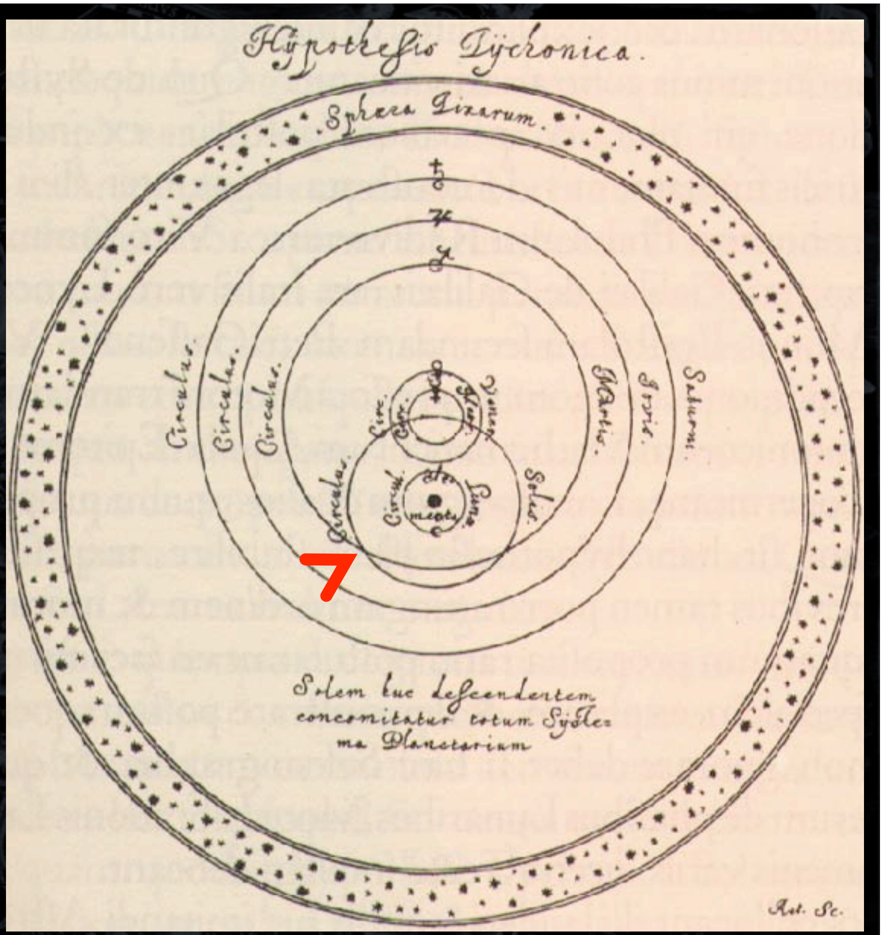
Physics: everyone knows the Earth is not in motion; we can feel it, or watch birds fly smoothly through the air.

Scripture: At the battle of Jericho, God ordered the sun to stand still in the sky — because usually it is moving.

Compromise Solution

Tychonic system, ca. 1583: the Earth really is at rest in the center; the moon and sun revolve around the Earth. *But* the other planets revolve around the sun.

Problem: orbit of *Mars*.



Tychonic system, 1588: Mars crosses the sun's path.

By the time he finished his analysis of the 1577 comet – in 1588 – he had all the pieces: no spheres, so no conflict.

Brighter Horizons

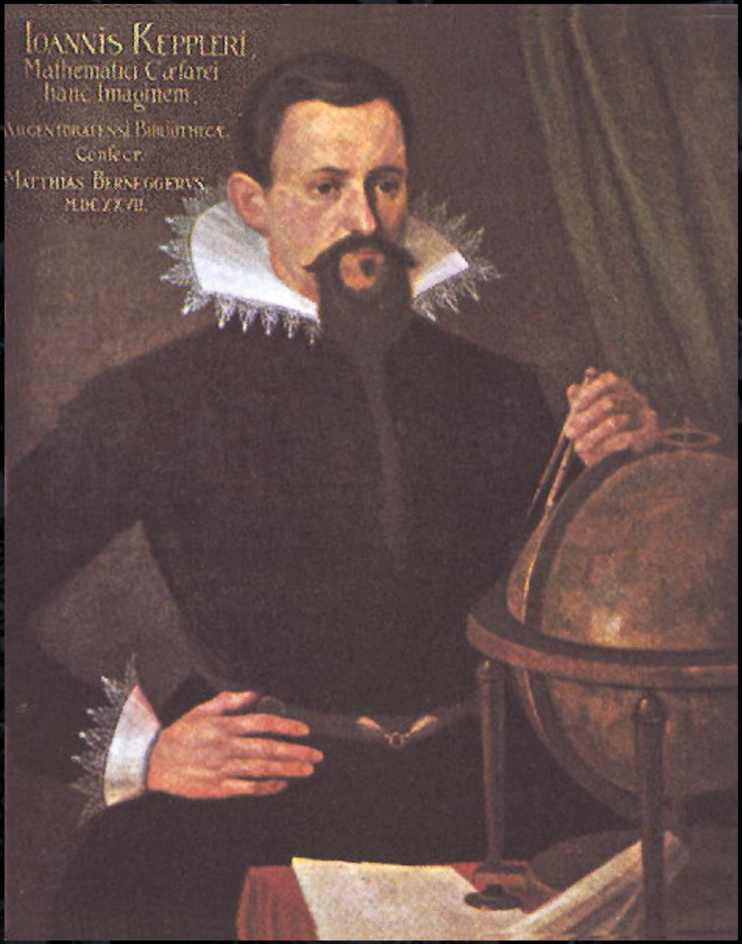
In the midst of this work, the King of Denmark died. His son saw little value in heaping unlimited funds on an arrogant, annoying, and seemingly useless astronomer. So Tycho had to find a new patron.

Eduard Ender, *Rudolph II and Tycho Brahe in Prague*, 1855

Tycho published a lavish book on his astronomical instruments and dedicated it to Emperor Rudolf II, Holy Roman Emperor, in Prague. It worked…

Kepler: Mystical Physics

Johannes Kepler (1571 – 1630) had been sickly as a child. His mother was nearly burned at the stake for witchcraft (Kepler got a last-minute stay). He went on to study under one of the earliest Copernican converts (1590s). Though he enjoyed math and astronomy, he planned to become a Lutheran minister.

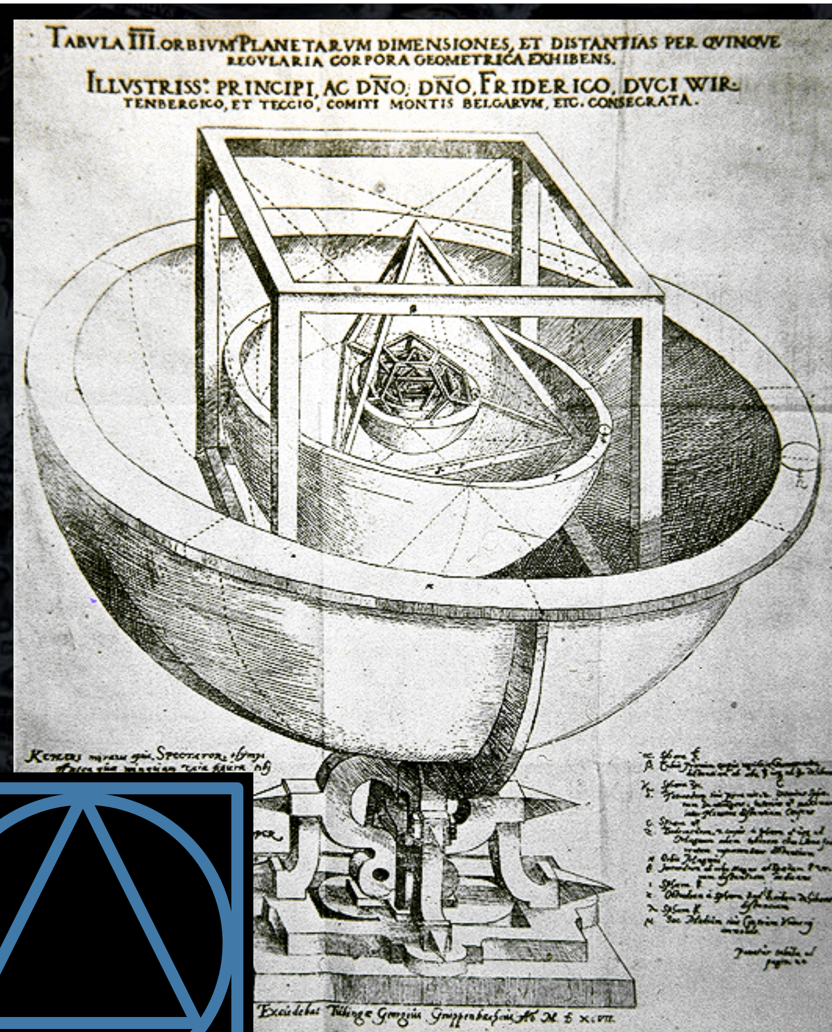


Anon., *Johannes Kepler*, 1627

His plans were scuttled when the math teacher in the Protestant seminary in Graz died, in 1594, and Kepler was summoned to replace him.

An Ordered Heavens

In the midst of a lecture in Graz in 1595, Kepler realized that the *number* and *arrangement* of the planets might be dictated by pure mathematics: embedding of perfect solids.



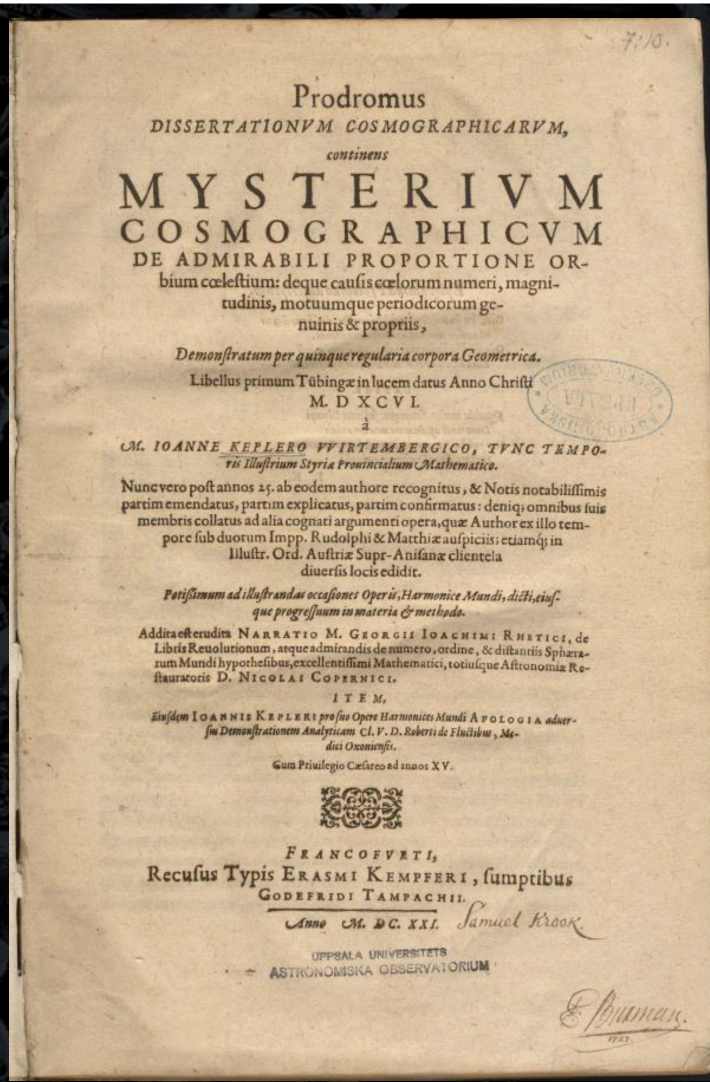
There only exist ***five*** perfect solids (pyramid, cube, octahedron, dodecahedron, and icosohedron).

Kepler hastily wrote *Mysterium Cosmographicum* (1596): there can only be six planets, and their spacing is determined geometrically.

Calling Card

Kepler sent copies of his book to all the known astronomers in Europe, along with flattering letters – he was desperate to get out of Graz and find a better position.

Tycho received the book and immediately contacted Kepler, since a competing astronomer (Ursus) had quoted an earlier flattering letter from Kepler.


Prodromus
DISSERTATIONVM COSMOGRAPHICARVM,
continens
MYSTERIVM
COSMOGRAPHICVM
DE ADMIRABILI PROPORTIONE ORbium cœlestium: deque causis cœlorum numeri, magnitudinis, motuumque periodicorum genuinis & propriis,
Demonstratum per quinque regularia corpora Geometrica.
Libellus primum Tübingæ in lucem datus Anno Christi M. D XCVI.
à
M. IOANNE KEPLERO VVIRTEMBERGICO, TVNC TEMPOris Illustrium Styriæ Provincialium Mathematico.
Nunc vero post annos 25. ab eodem authore recognitus, & Notis notabilissimis partim emendatus, partim explicatus, partim confirmatus: deniq; omnibus suis membris collatus ad alia cognati argumenti opera, quæ Author ex illo tempore sub duorum Impp. Rudolphi & Matthiæ auspiciis; etiamq; in Illustr. Ord. Austriæ Supr-Anisanæ clientela diuersis locis edidit.
Potissimum ad illustrandas occasiones Operis, Harmonice Mundi, dicti, eiusque progressuum in materia & methodo.
Addita est erudita NARRATIO M. GEORGII IOACHIMI RHETICI, de Libris Reuolutionum, atque admirandis de numero, ordine, & distantiis Sphærarum Mundi hypothesibus, excellentissimi Mathematici, totiusque Astronomiæ Restauratoris D. NICOLAI COPERNICI.
ITEM,
Eiusdem IOANNIS KEPLERI pro suo Opere Harmonices Mundi APOLOGIA aduersus Demonstrationem Analyticam Cl. V. D. Roberti de Fluctibus, Medici Oxoniensis.
Cum Priuilegio Cæsareo ad annos XV.
FRANCOFVRTI,
Recusus Typis ERASMI KEMPFERI, sumptibus GODEFRIDI TAMPACHII.
Anno M. DC. XXI.
Samuel Krook

It worked: In 1600, Kepler joined Tycho as Imperial Mathematician at Rudolf II's court.

"Warfare on Mars"

Tycho's assignment: work out a geometrical description of Mars's motion, adequate to Tycho's unprecedented observational data.

Kepler boasted that it would take him about a week … and instead it took him five years.

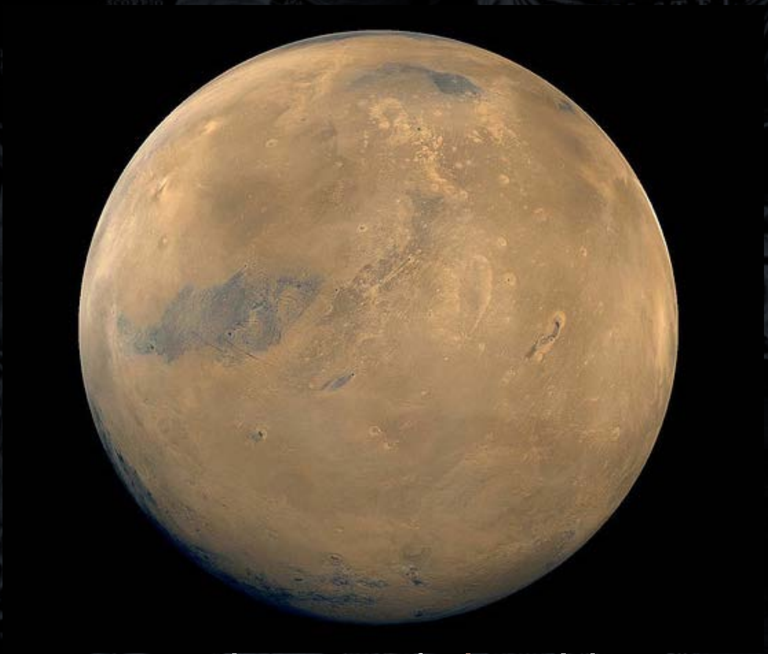


Photo courtesy of andyz on Flickr.

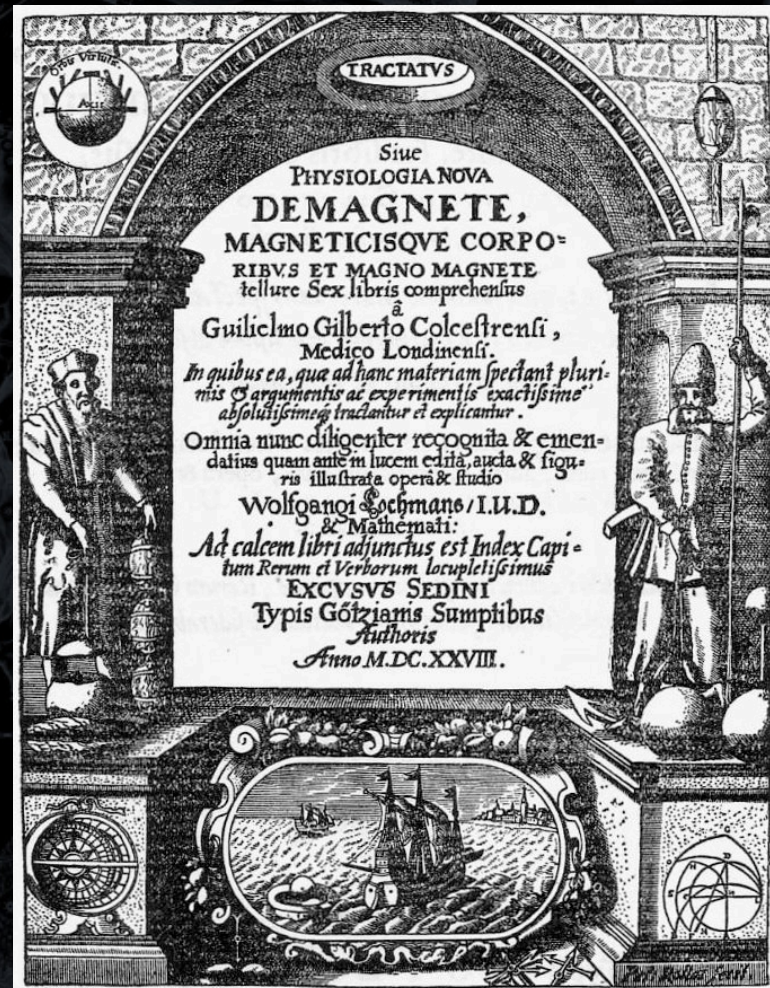
Mars, as seen by the Hubble Space Telescope

Kepler had a unique vantage point. His access to Tycho's unprecedented data, combined with Tycho's demonstration that there were no crystalline spheres, freed Kepler to tinker with unusual geometrical arrangements.

Solar Physics

Around the time he moved to Prague, Kepler read Gilbert's *De Magnete* (1600). Now Kepler began to think of the sun in terms of *magnetism*: perhaps it exerted a physical (attractive) force on the planets.

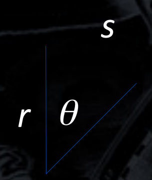
Kepler was thus the first to begin thinking about Copernicanism in terms of *physics*: there was a reason to reckon planetary motion with respect to the sun.


TRACTATVS
Siue
PHYSIOLOGIA NOVA
DE MAGNETE,
MAGNETICISQVE CORPO-
RIBVS ET MAGNO MAGNETE
tellure Sex libris comprehensus
à
Guilielmo Gilberto Colcestrensi,
Medico Londinensi.
In quibus ea, quæ ad hanc materiam spectant pluri-
mis & argumentis ac experimentis exactissime
absolutissimeq; tractantur et explicantur.
Omnia nunc diligenter recognita & emen-
datius quam ante in lucem edita, aucta & figu-
ris illustrata operâ & studio
Wolfgangi Lochmans/I.U.D.
& Mathemati:
Ad calcem libri adjunctus est Index Capi-
tum Rerum et Verborum locupletissimus
EXCVSVS SEDINI
Typis Götzianis Sumptibus
Authoris
Anno M.DC.XXVIII.

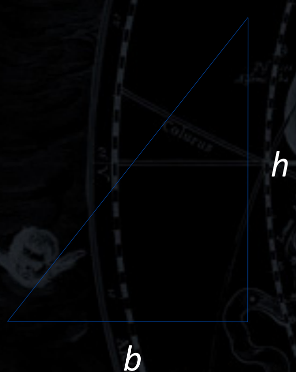
Walter Gilbert, *De Magnete*, 1600

Kepler mixed this "modern"-sounding approach with sun-mysticism: the sun is like a god sitting in its throne, around which all else revolves.

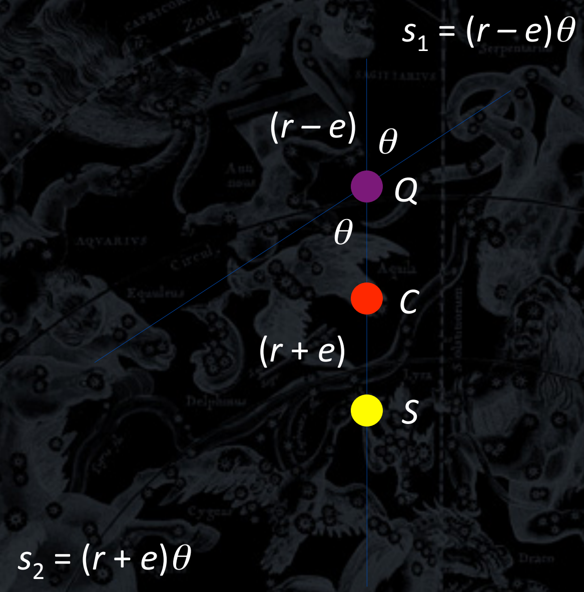
Tinkering Toward The Second Law

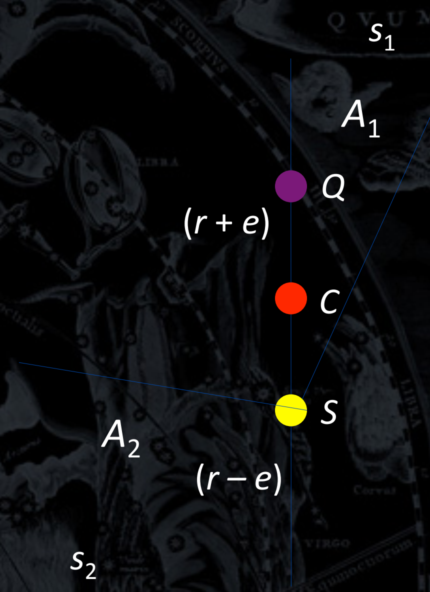


Arclength: $s = r\theta$



Area = $(1/2)\ bh$





Equant: planet traverses equal *angles* in equal times, as reckoned from *Q*.

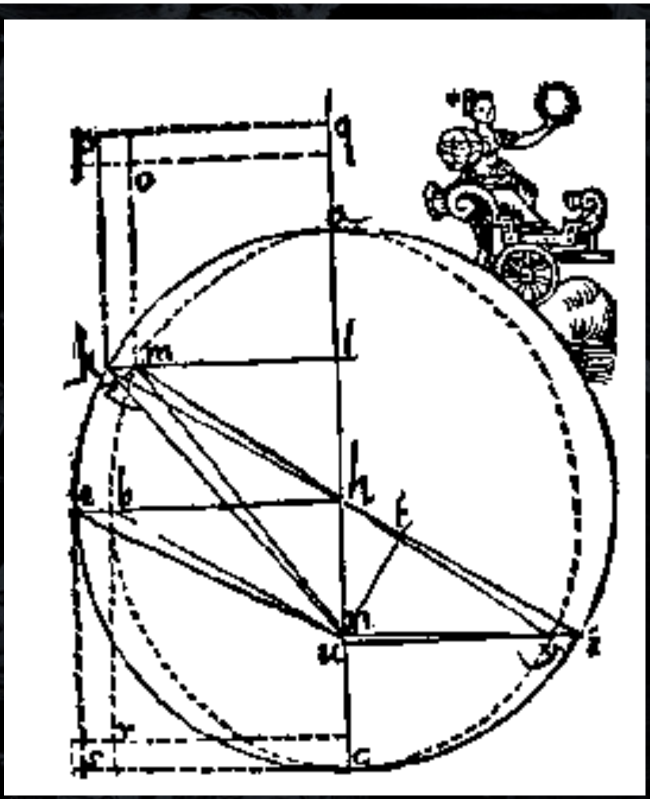
Kepler: planet traverses equal *areas* in equal times, as reckoned from *S*.

$$A_1 = (1/2)\ s_1\ (r + e) = (1/2)\ (r - e)\ \theta\ (r + e)$$
$$A_2 = (1/2)\ s_2\ (r - e) = (1/2)\ (r + e)\ \theta\ (r - e)$$

Given his magnetic analogy, Kepler argued that the planets *should* speed up as they near the sun: hence they cover greater area in equal time.

Not A Circle?

When he tried to fit *r* and *e* for Mars's orbit using Tycho's data, Kepler hit a problem. Any three points can define a circle; yet Kepler kept getting *different* circles for any triple of data points. Perhaps Mars's orbit was *not* a perfect circle, but some sort of *oval.*



Kepler, *Astronomia Nova,* 1609

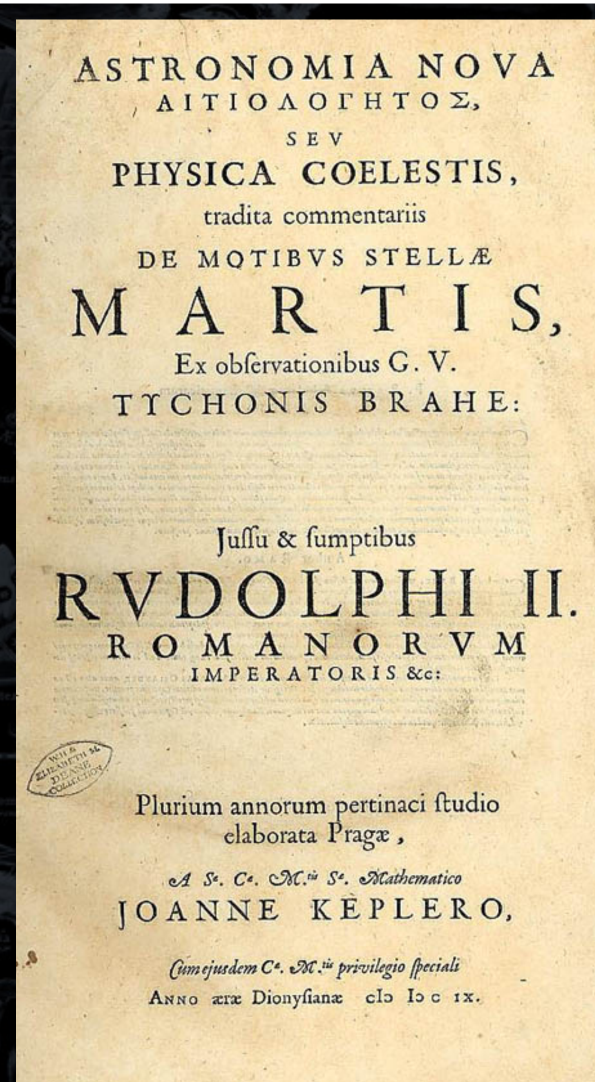
Since Kepler didn't know the oval's shape, he used an *ellipse* as a first approximation. The ellipse was meant to be a *temporary* and *convenient* stand-in for the real curve.

The New Astronomy

Kepler published these results in his *Astronomia Nova: Physica Coelestis* (1609). He announced two laws:

1. Planets move on *ellipses*, with the sun at one focus.
2. Planets sweep out equal areas in equal times, as measured from the sun.

Both had emerged as convenient approximations rather than "laws."


ASTRONOMIA NOVA
ΑΙΤΙΟΛΟΓΗΤΟΣ,
SEV
PHYSICA COELESTIS,
tradita commentariis
DE MOTIBVS STELLÆ
MARTIS,
Ex obſervationibus G. V.
TYCHONIS BRAHE:
Juſſu & ſumptibus
RVDOLPHI II.
ROMANORVM
IMPERATORIS &c:
Plurium annorum pertinaci ſtudio
elaborata Pragæ,
A Se. Ce. M.tis Se. Mathematico
JOANNE KEPLERO,
Cum ejusdem Ce. M.tis privilegio ſpeciali
ANNO æræ Dionyſianæ cIɔ Iɔ c IX.

Kepler's approach combined speculative physics, number-mysticism, calculational convenience, and Tycho's empirical data.

Watershed, Reprise

In many ways, Tycho and Kepler were strikingly modern:

how to run an observatory;
how to collect and systematize empirical data;
how to apply physics to astronomy;
how to break with ancient authorities over uniform circular motion and crystalline spheres;
how to treat motions of bodies...

Image "The Sleepwalkers: A History of Man's Changing Vision of the Universe," Arthur Koestler, removed due to copyright restrictions.

... and yet these modern-looking developments came couched in decidedly un-modern activities:

astrology and alchemy;
number-mysticism;
theological critiques;
charges of witchcraft;
Renaissance patronage;
lack of clear distinction between private correspondence and publication

STS.003 The Rise of Modern Science
Fall 2010