Astronomy 350L

(Fall 2006)

The History and Philosophy of Astronomy

(Lecture 10: Tycho/Kepler II)

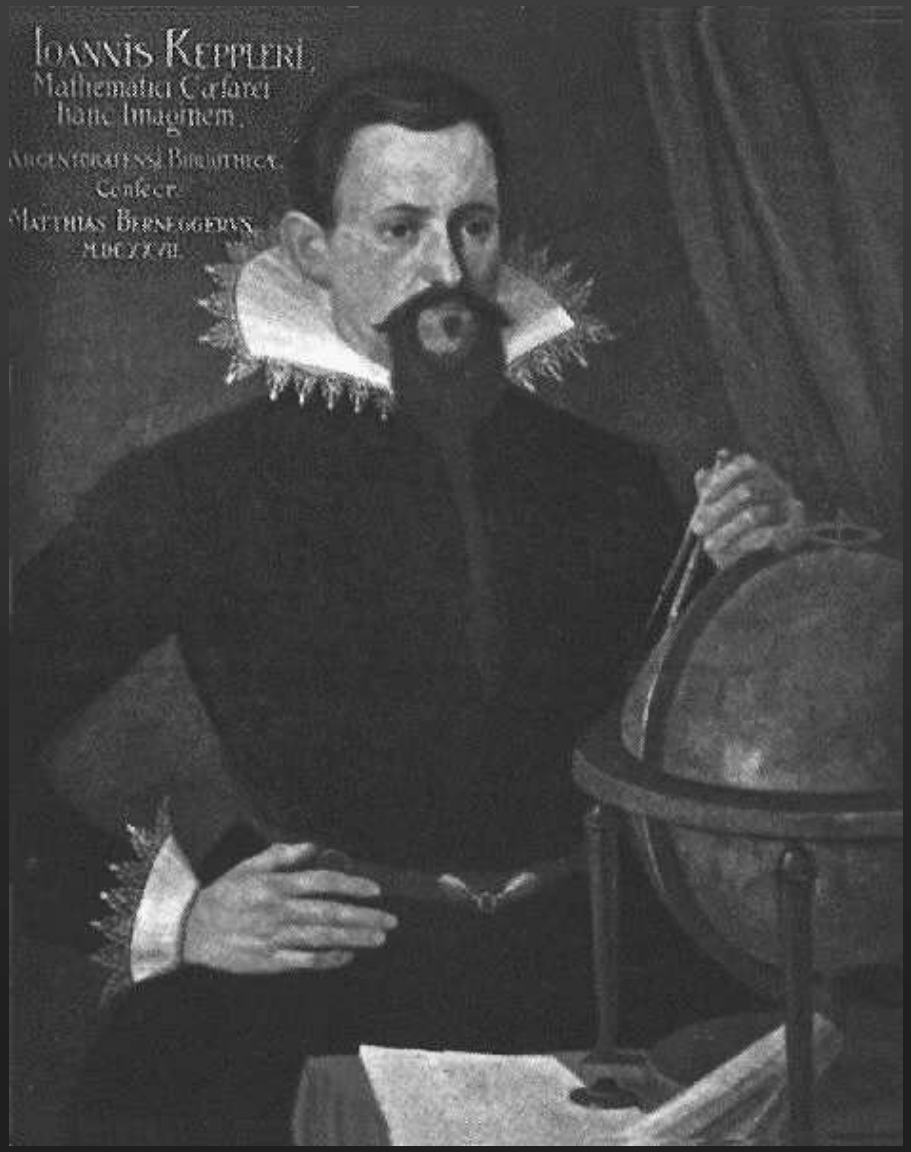
Instructor: Volker Bromm
TA: Jarrett Johnson

The University of Texas at Austin

Tycho and Kepler meet in Prague (1600-01)

- Tycho needs Kepler:
  - difficult calculations to figure out orbit of Mars
- Kepler needs Tycho:
  - precision data to figure out true orbits of the planets
- Together embark on improved astron. tables (*Tabulae Rudolphinae*)

Johannes Kepler: The Great Theorist



- 1571 – 1630
- born into middle-class:
  - lifelong economic struggles
- completed Copernicus agenda
- The last mystic (last scientific astrologer)

Kepler: Geography of his Life

Europe: Deeply divided into multiple confessions

Kepler: Birth and Upbringing in Wuerttemberg

- Born 1571: Weil der Stadt (near Stuttgart)
- middle-class family
- father: a mercenary, mother: cantankerous

University Education at Tuebingen (1589-94)

- Leading Protestant University
- Undergrad (7 Liberal Arts)
- (Lutheran) Theology

University Education at Tuebingen (1589-94)

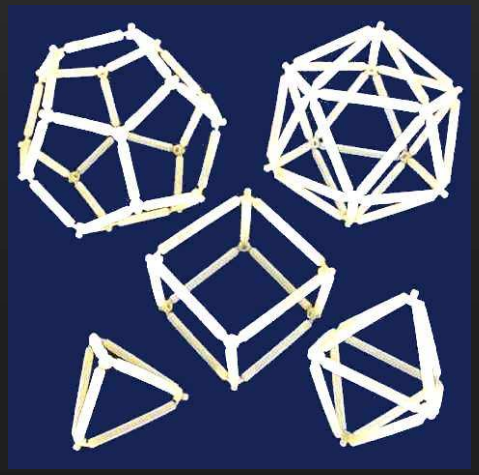
- Michael Maestlin, professor of mathematics and astronomy
- taught: Ptolemy *and* Copernicus
- lifelong friendship with Kepler

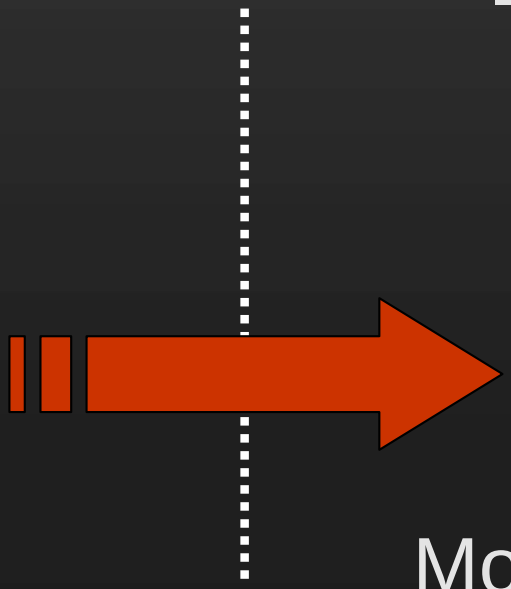
Neoplatonism: Search for hidden harmony

God

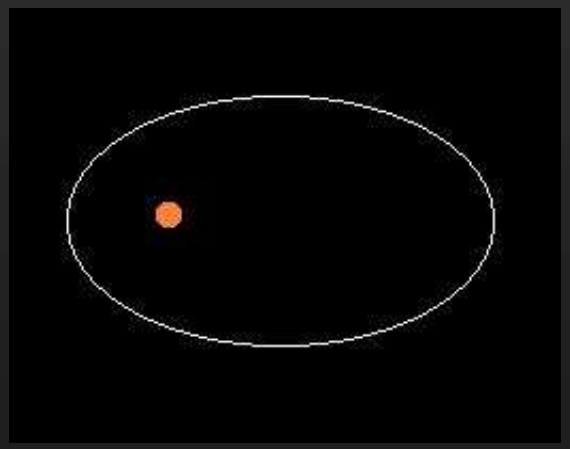
(William Blake, 1757-1827)

Realm of Ideas





Realm of Experience



Motion of planets

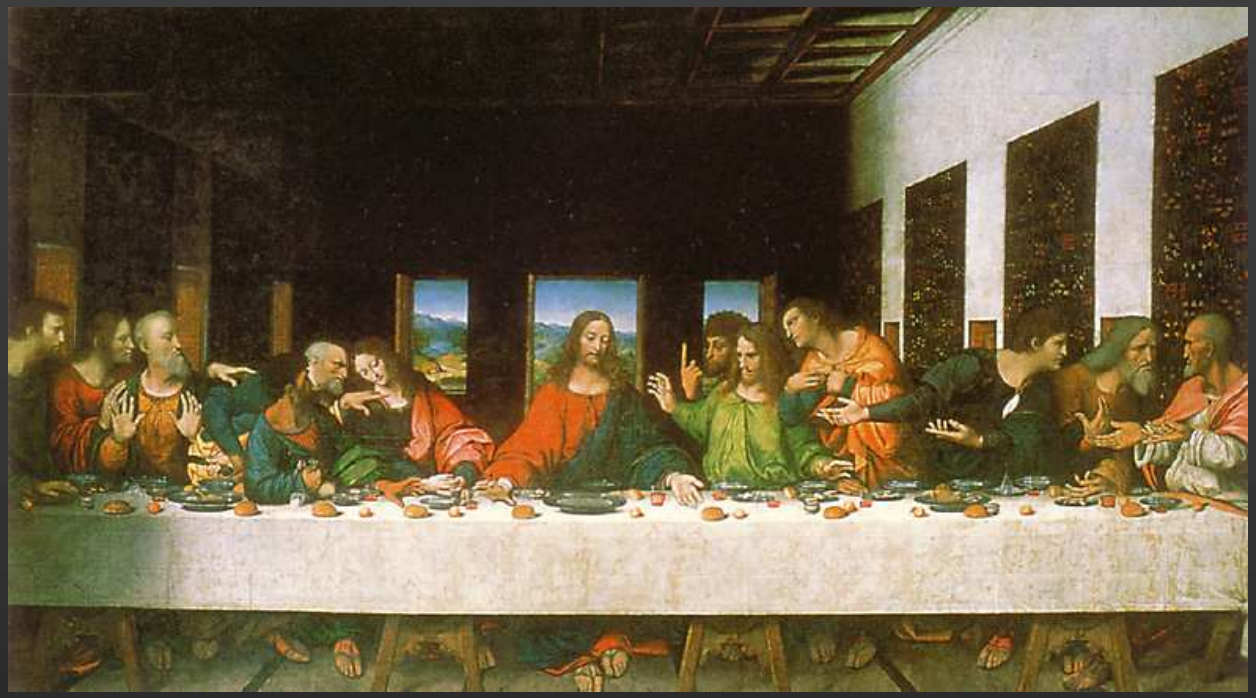
Neo-Pythagoreanism: A Universe governed by Numbers

Divine Tetractys:

1 + 2 + 3 + 4 = 10

- symbolizes the universe!

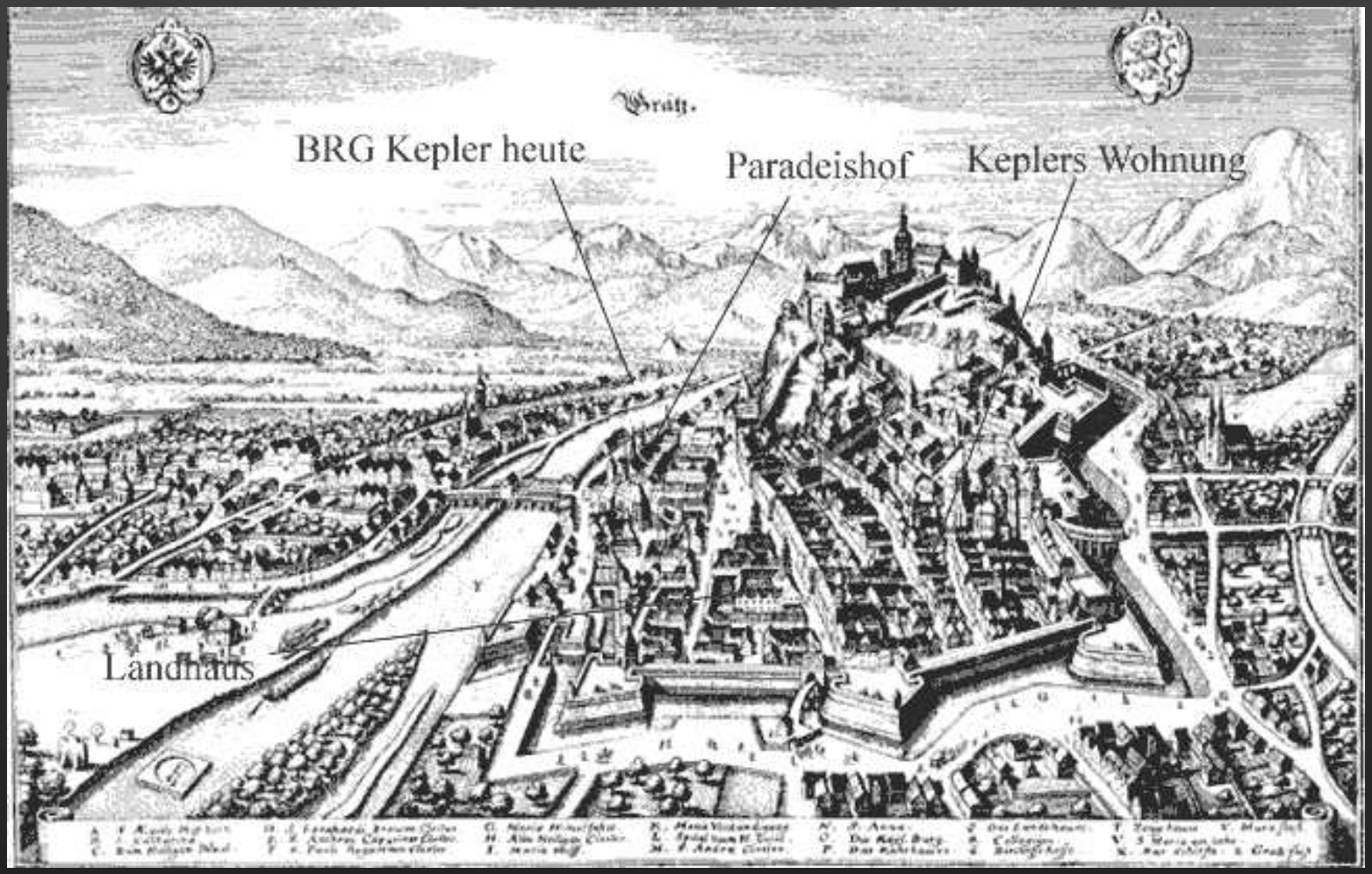
Kepler studies Theology and makes Enemies



- “Last Supper Controversy”:
  - Lutherans: Wine *is* Christ
  - Calvinists: Wine only *symbolizes* Christ
- Kepler, being a Lutheran, supports Calvinist view
- Source of great trouble, professionally and personally

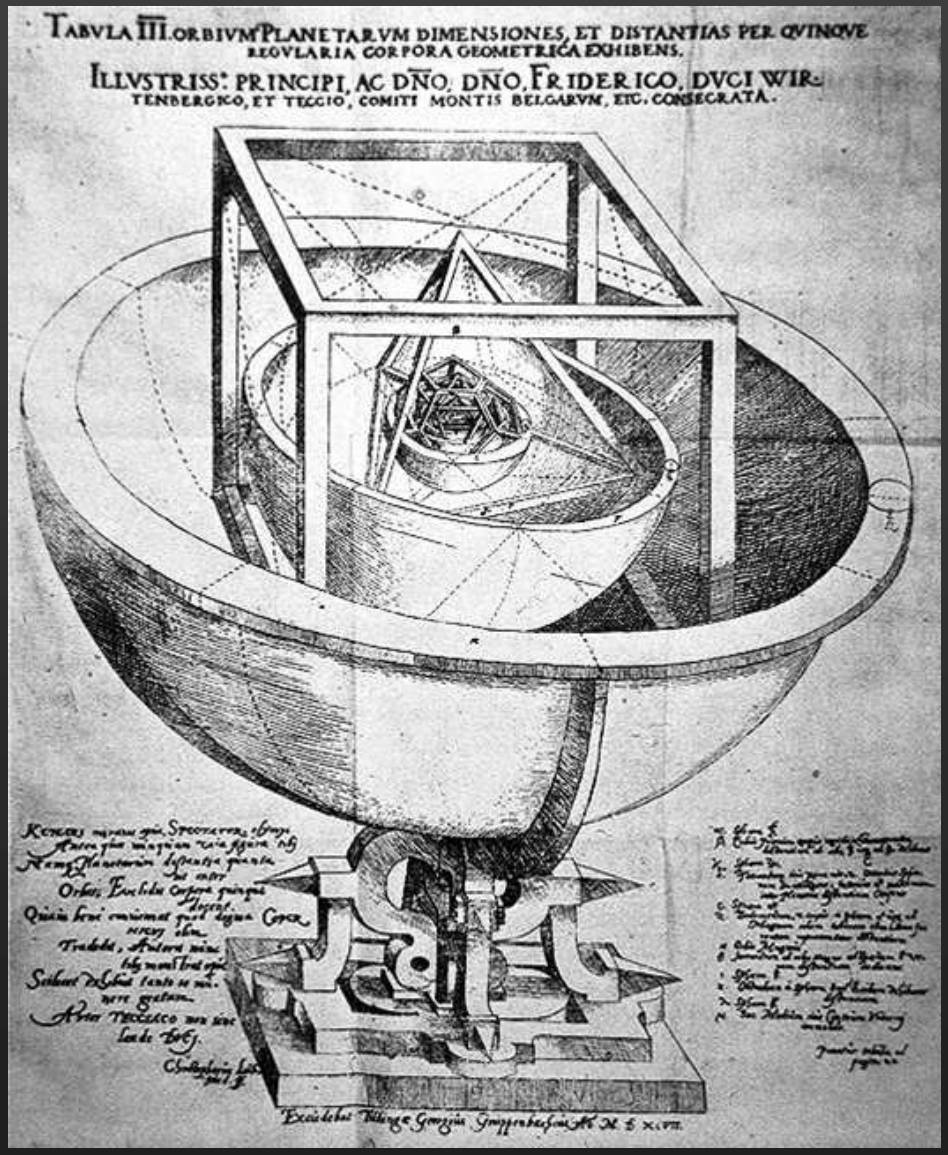
Mathematician in Graz (Austria)

Mathematician in Graz



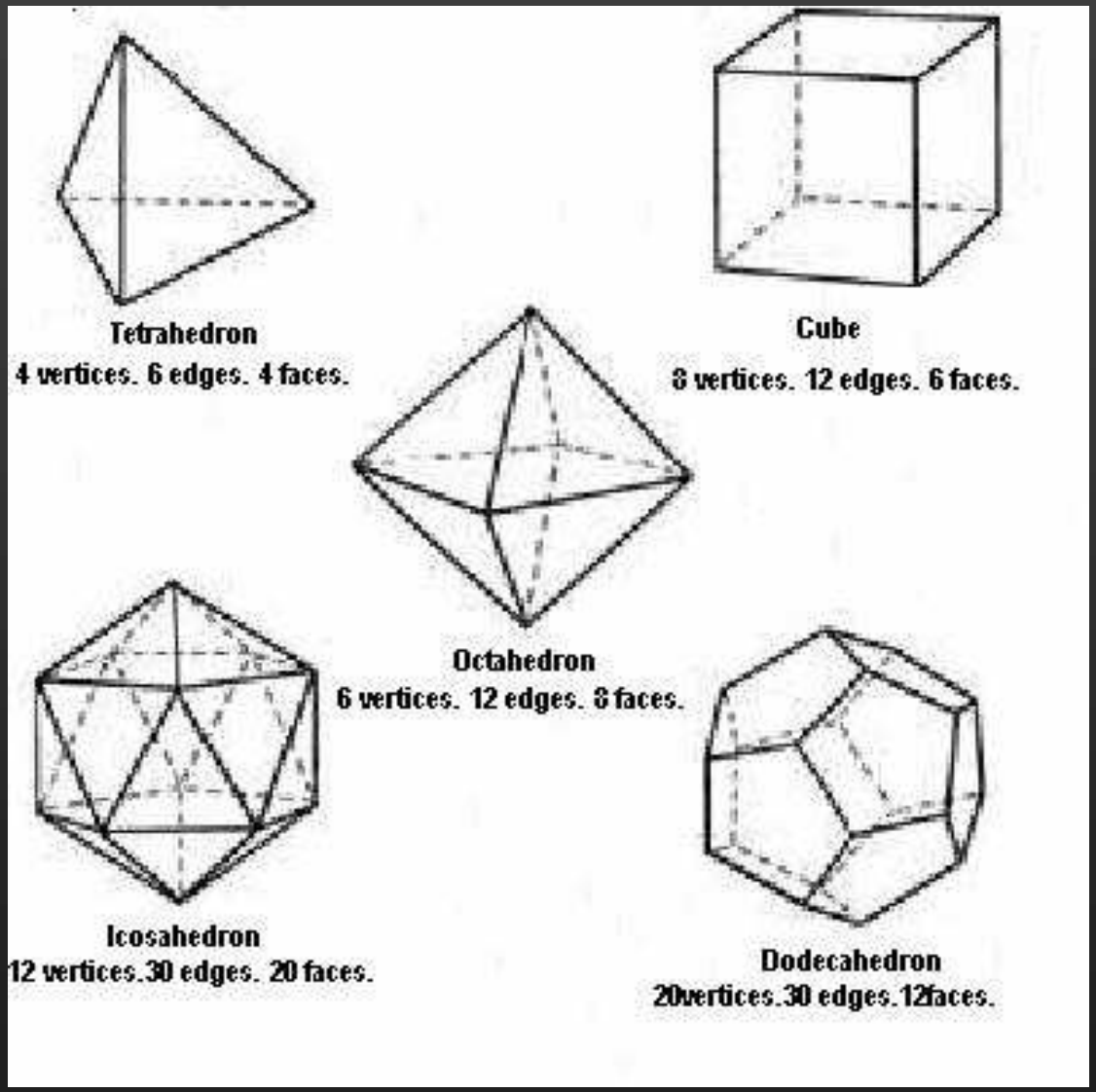
- Teacher at Protestant High School
- Styrian estate mathematician: horoscopes

Mysterium Cosmographicum

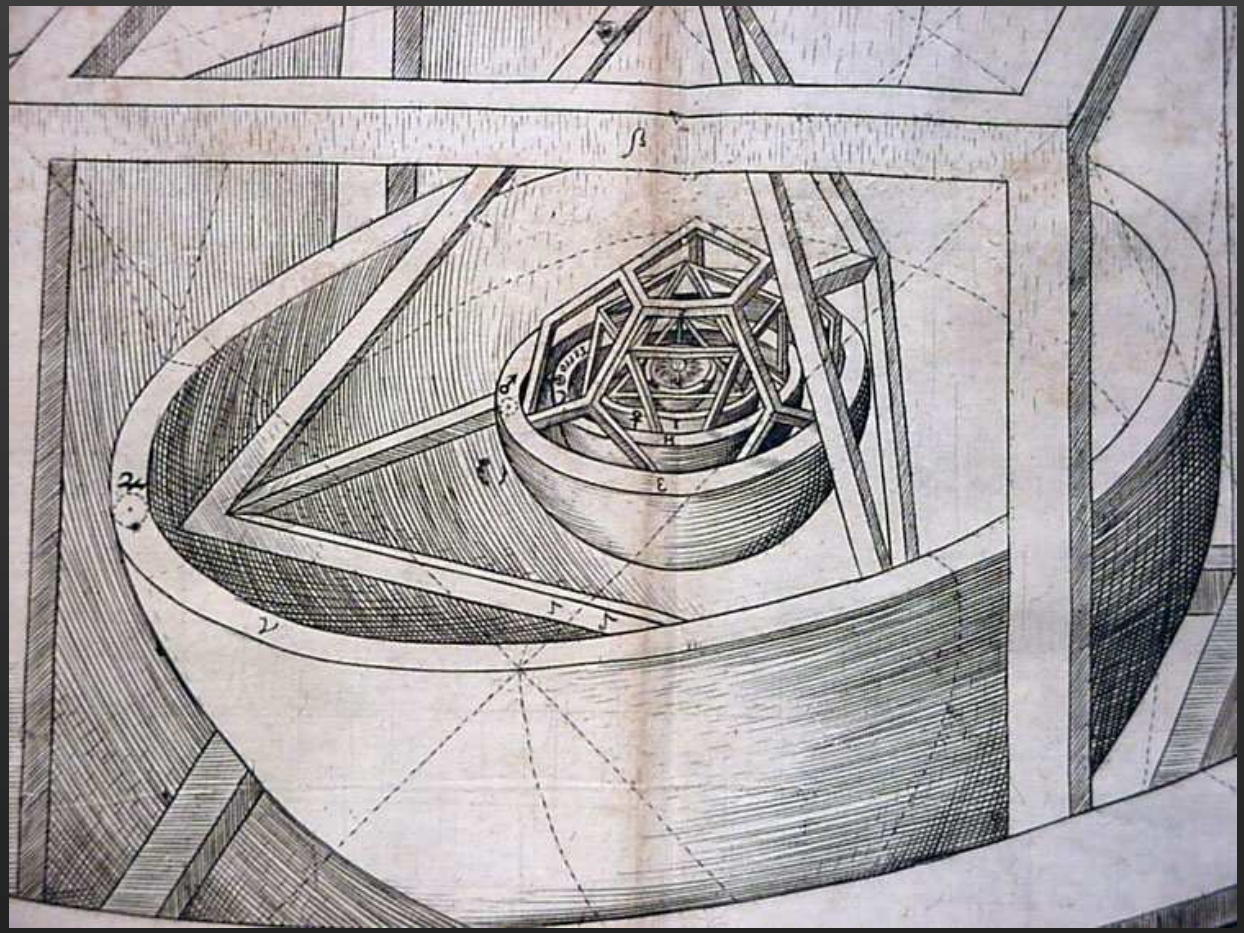


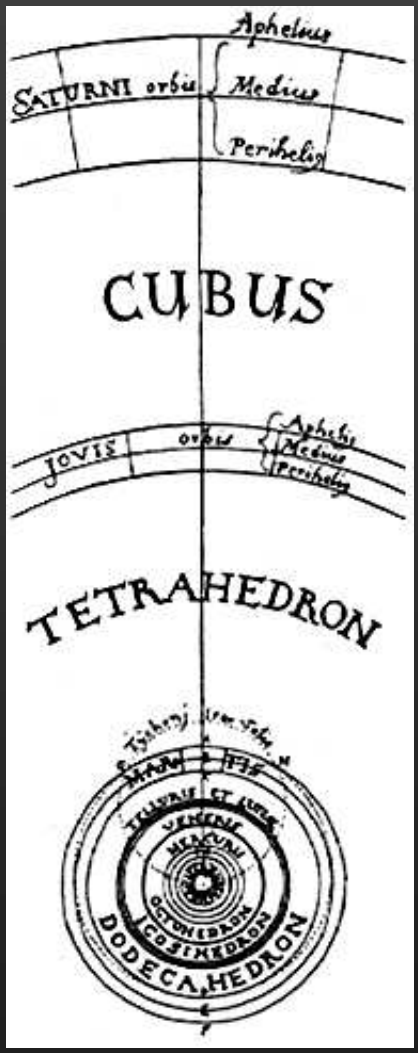
- Why are there exactly six planets?
- What determines their distances from the Sun?
- *Cosmographic Mystery* (1596)

Mysterium Cosmographicum: 5 Platonic Solids



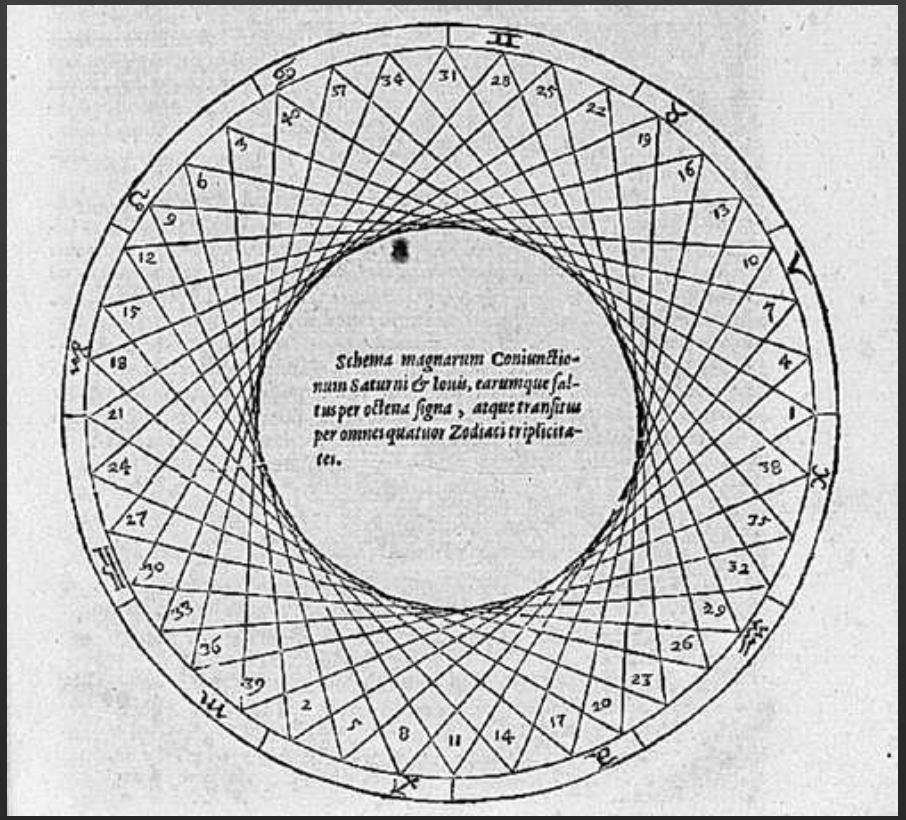
Mysterium Cosmographicum





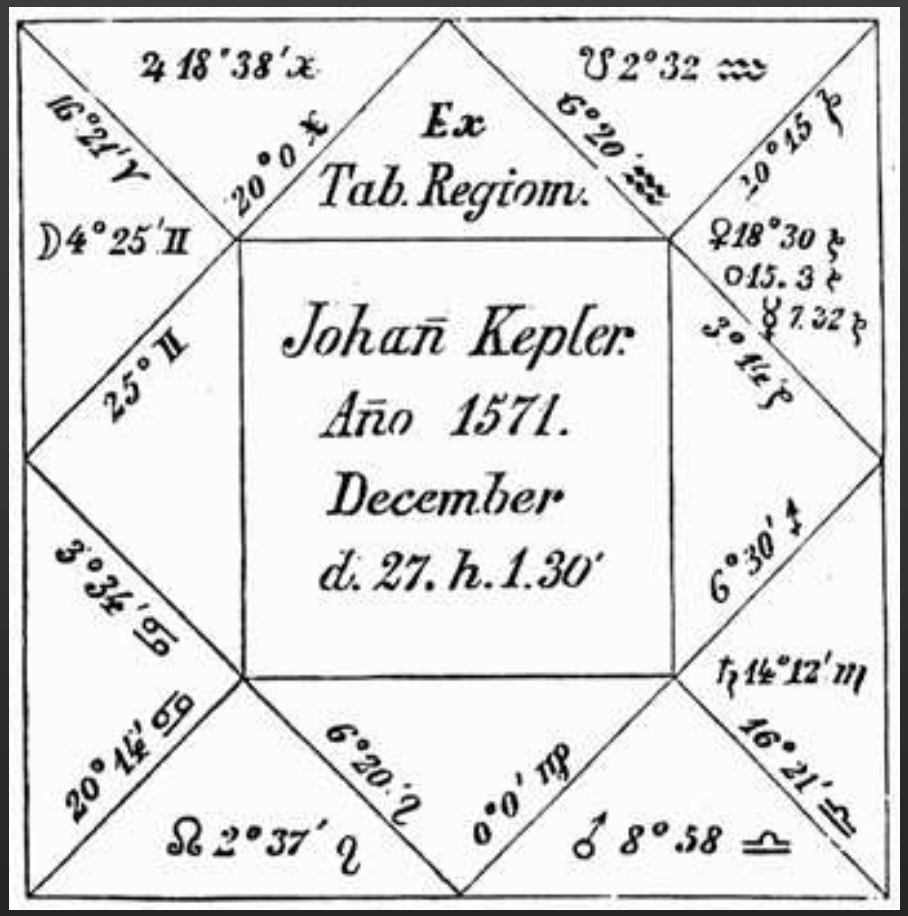
- planetary orbits nested between Platonic solids!

Kepler and Astrology



- One of his duties: Work out annual calendars, i.e., predict the events of the year ahead!

Kepler and Astrology



(Kepler's nativity)

- Kepler: one of the last scientific astrologers!
- Henceforth, astronomy and astrology part company

Kepler: Fleeing the Counter Reformation in Graz

Kepler: Move to Imperial Prague

Rudolph II
- Emperor (1576-1612)

- Great Patron of Arts and Sciences (Tycho, Kepler)

Tycho’s Assistant in Imperial Prague

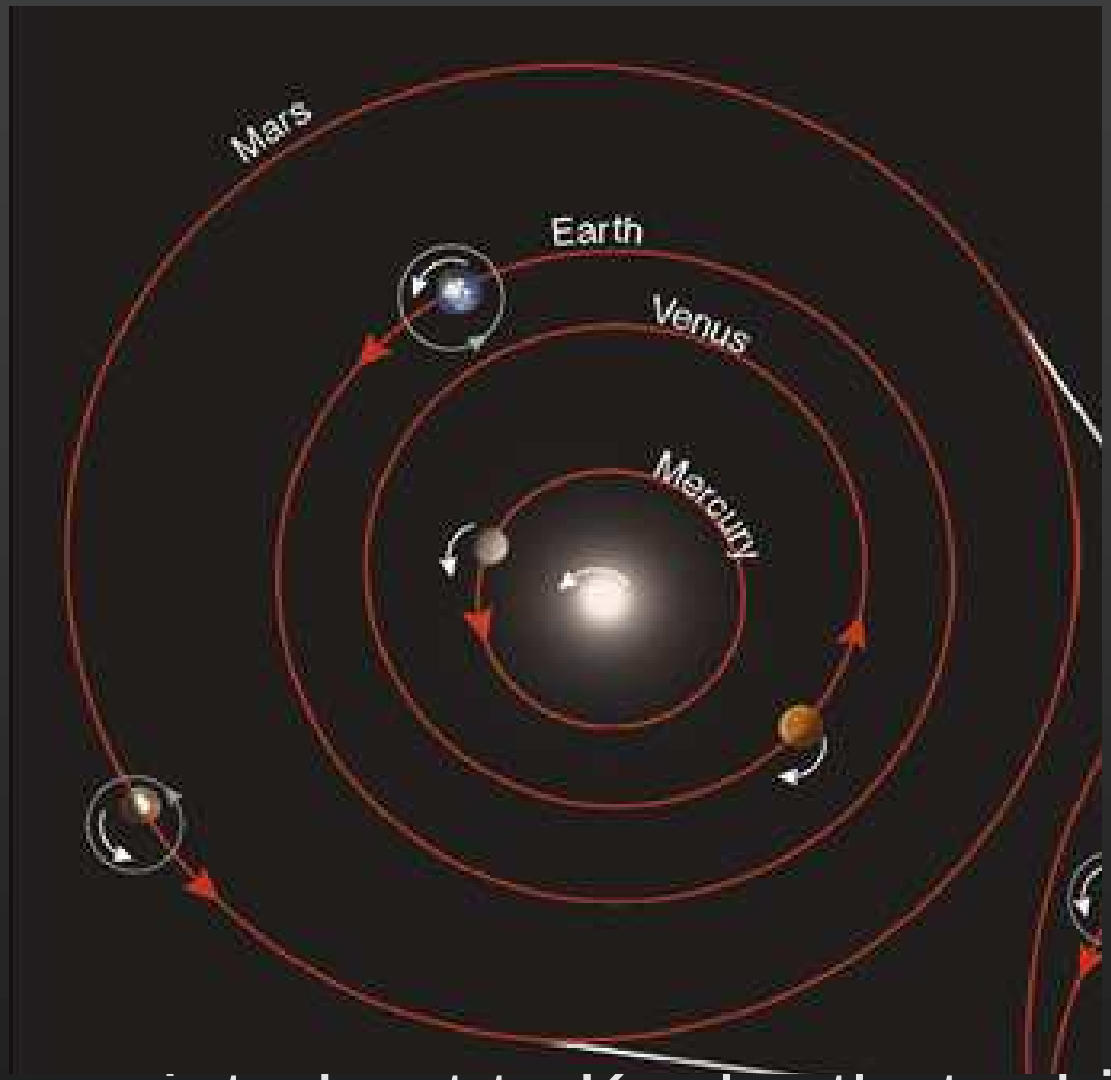
Benatky Castle: Tycho’s Final Domicile (1599 – 1601)

- Tycho invites upstart young Johannes Kepler!

Kepler: The Inheritor of Tycho

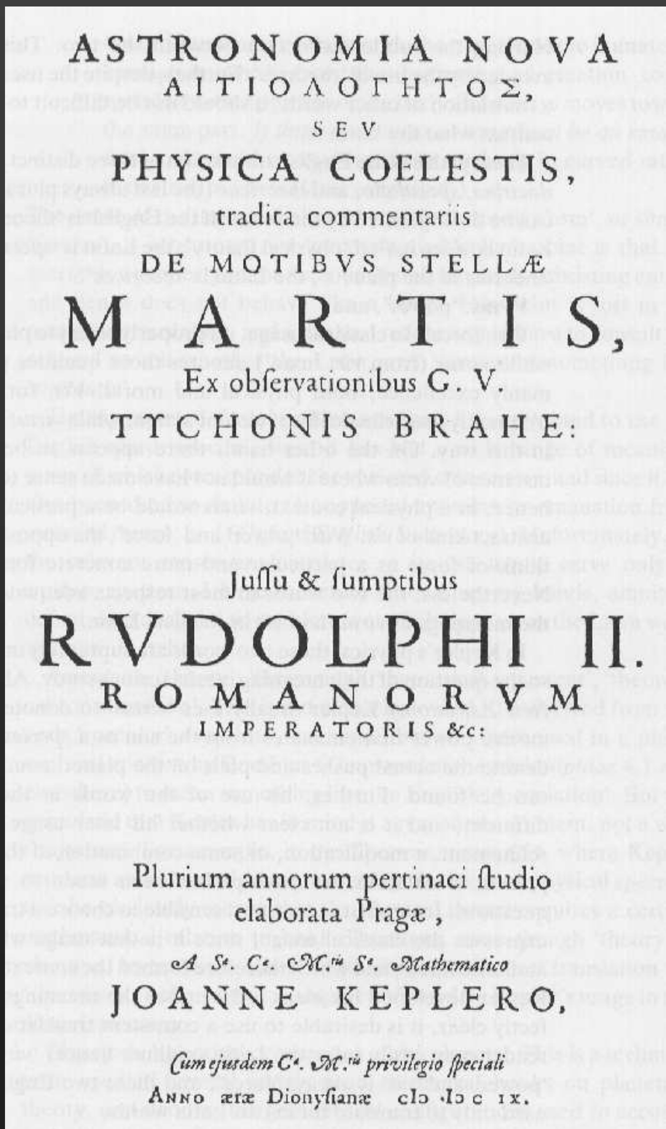
- After Tycho’s death (1601): Kepler moves quickly to get hold of Tycho’s data
- Emperor Rudolph II appoints Kepler to become Imperial Mathematician
- Imperial order: Complete *Rudolphine Tables*
- Kepler’s main agenda: Win the “battle with Mars”

Kepler's ``Warfare'' with Mars



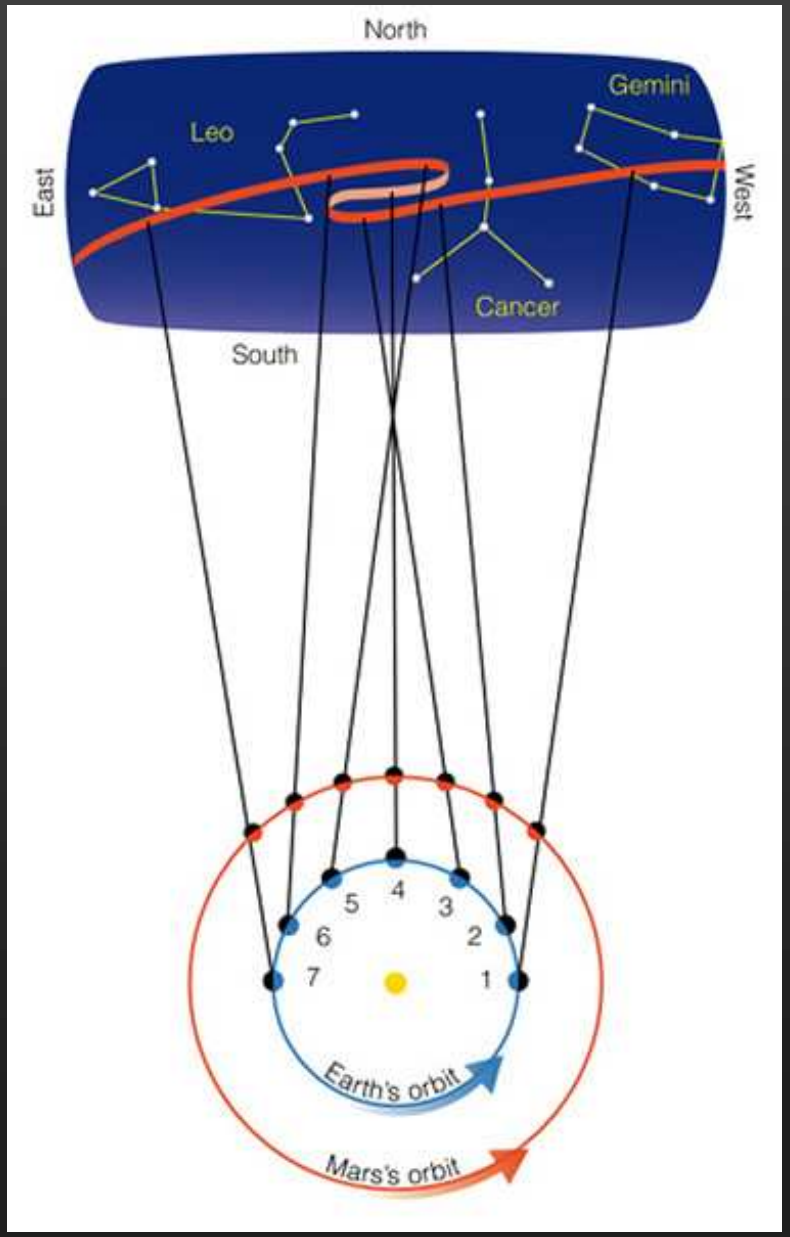
- Tycho pointed out to Kepler that orbit of Mars is particularly difficult to understand!
- Orbit of Mars shows large deviation from circularity!

The New Astronomy: The Orbits of the Planets


ASTRONOMIA NOVA
ΑΙΤΙΟΛΟΓΗΤΟΣ,
SEV
PHYSICA COELESTIS,
tradita commentariis
DE MOTIBVS STELLÆ
MARTIS,
Ex obſervationibus C. V.
TYCHONIS BRAHE:
Juſſu & ſumptibus
RVDOLPHI II.
ROMANORVM
IMPERATORIS &c:
Plurium annorum pertinaci ſtudio
elaborata Pragæ,
A S. C. M.tis S. Mathematico
JOANNE KEPLERO,
Cum ejusdem C. M.tis privilegio ſpeciali
Anno æræ Dionyſianæ cIↃ IↃ c ix.

- Astronomia Nova (New Astronomy, 1609)
- Kepler's 1st and 2nd Law:
  - planets move in elliptic orbits with Sun in one focus
  - law of areas
- Finally: A model that works!
- Introduce Celestial Physics

The New Astronomy: The Orbits of the Planets

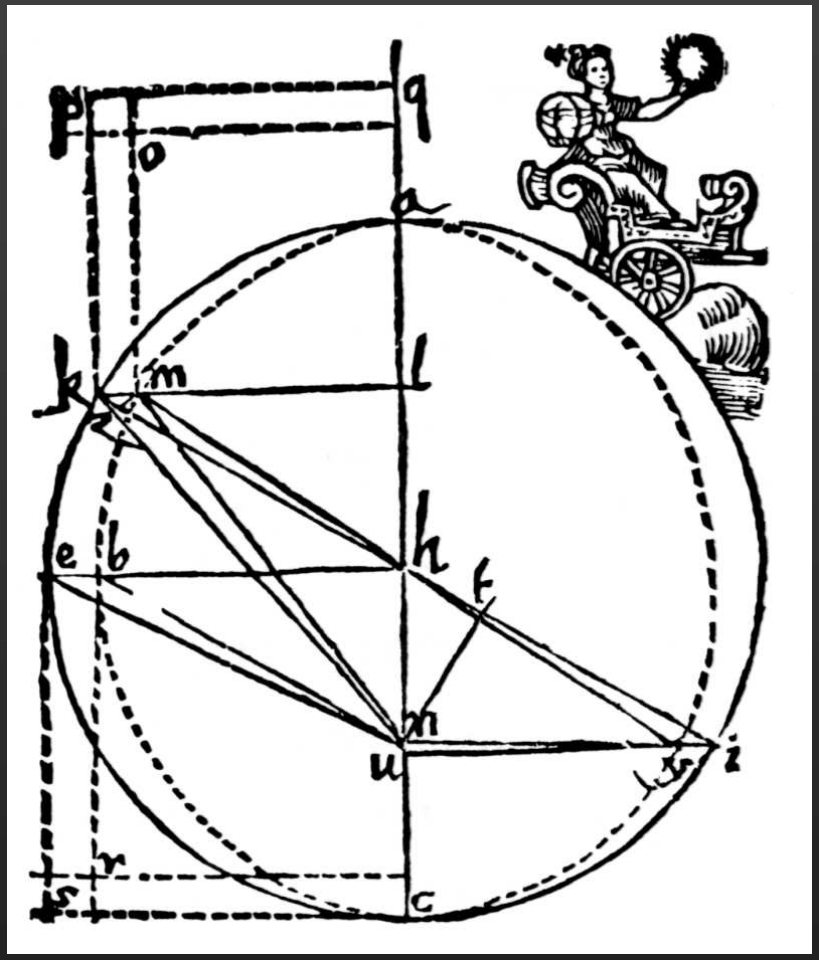


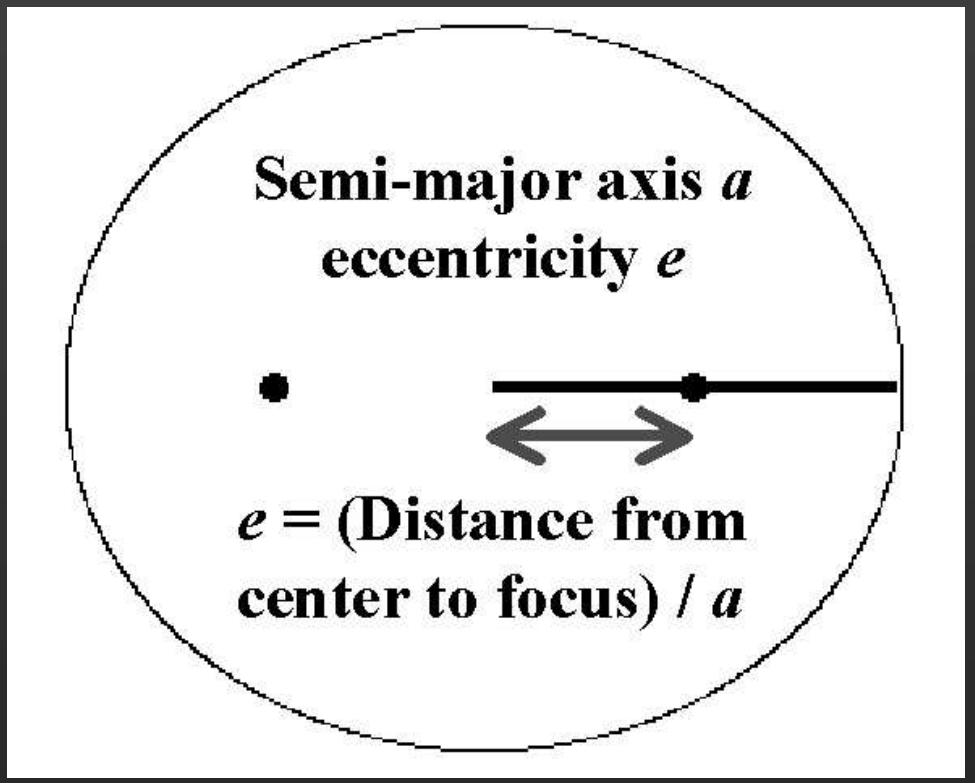
- Problem: Observe (Mars-orbit) from moving platform (Earth)!
- But want to figure out orbit with respect to Sun!
- A convolved problem!

Long Process of Trial-and-Error

- Method: (1) Try given orbital geometry, and
  (2) compare with Tycho's data
- All combinations involving *circles*, can only give accuracy of ~ 8 arcmin
- But: Kepler knew that Tycho's data have accuracy of ~ 4 arcmin
- Thus: Reject circular orbits!
- Eventually: Try elliptic orbits with Sun in one focus!

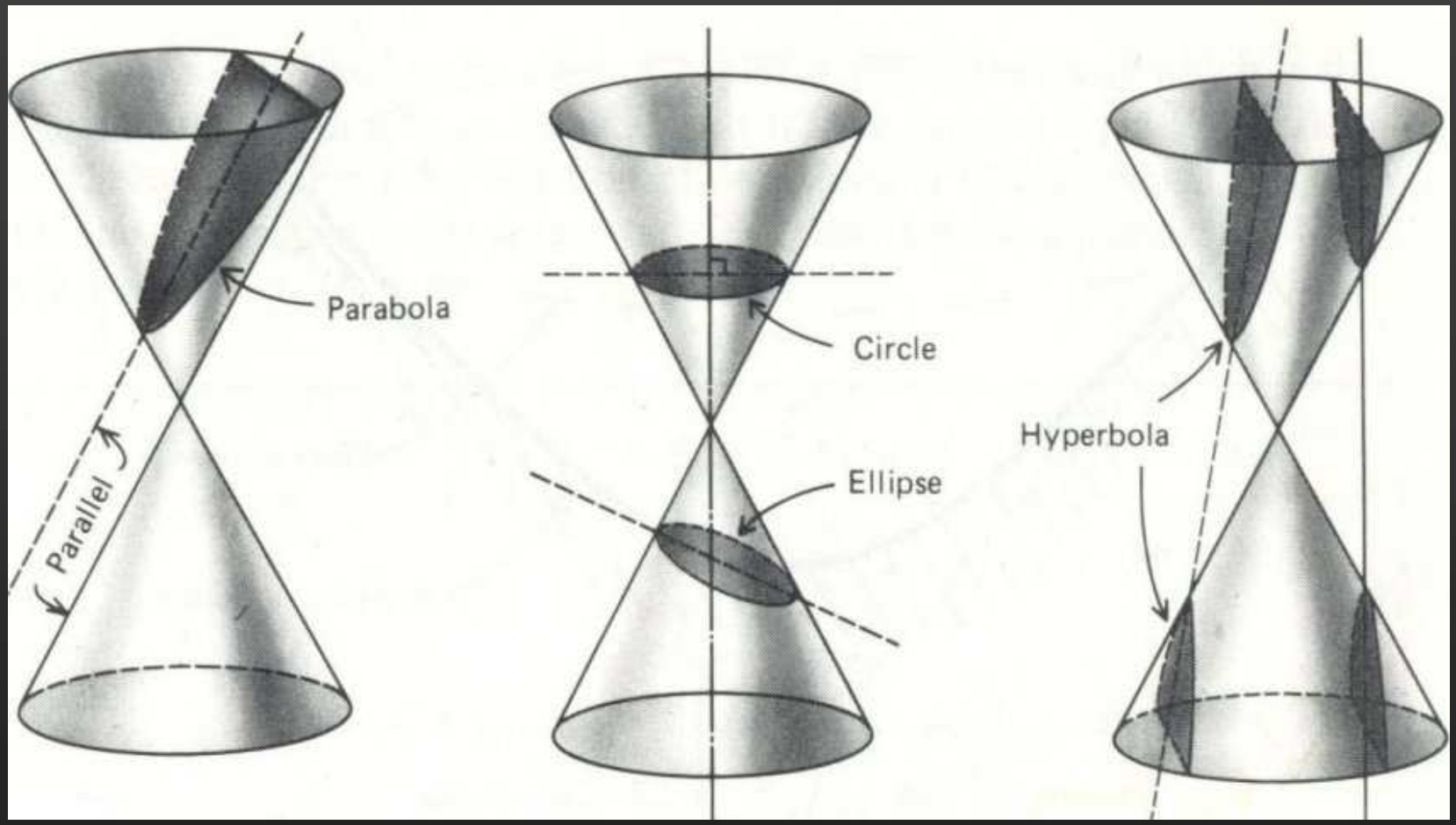
Orbit of the Planets: Kepler's 1st Law





- 1st Law: Planets move in ellipses with the Sun in one focus!

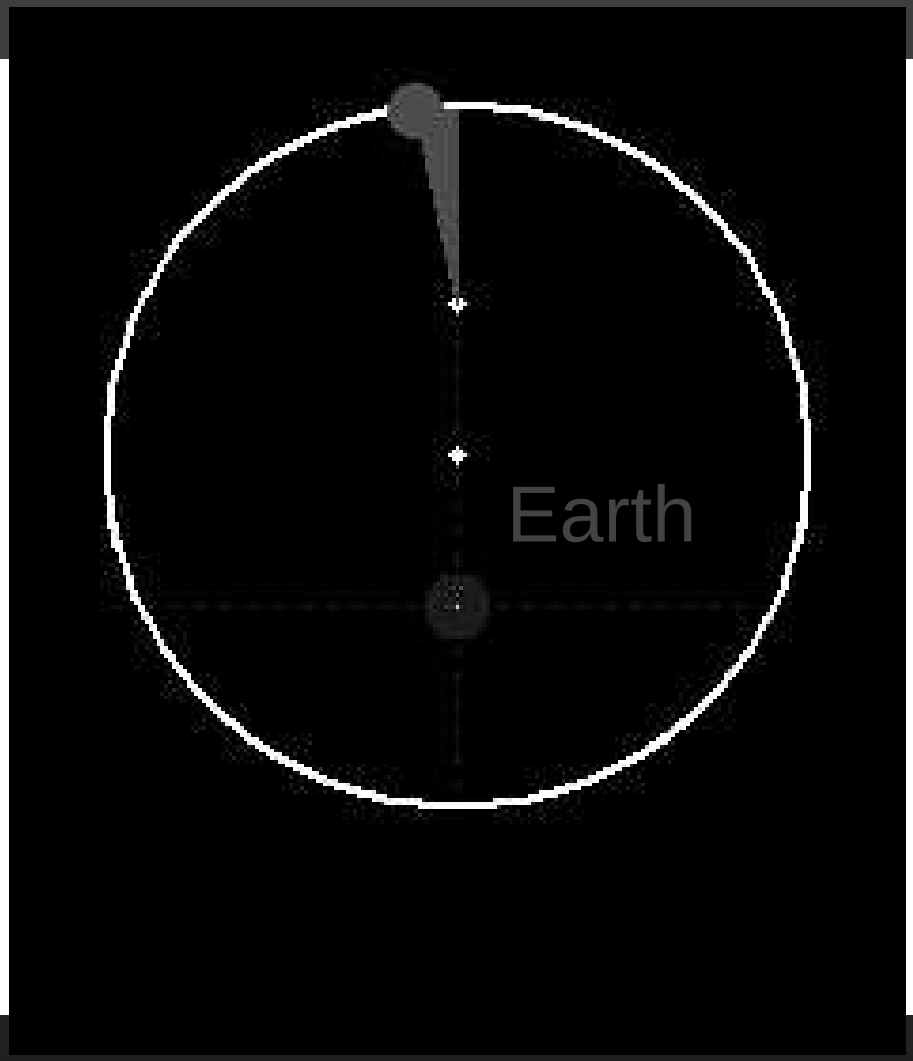
Orbit of the Planets: Kepler's 1st Law



- Ellipse is one of the three conic sections, and the circle is a special case!

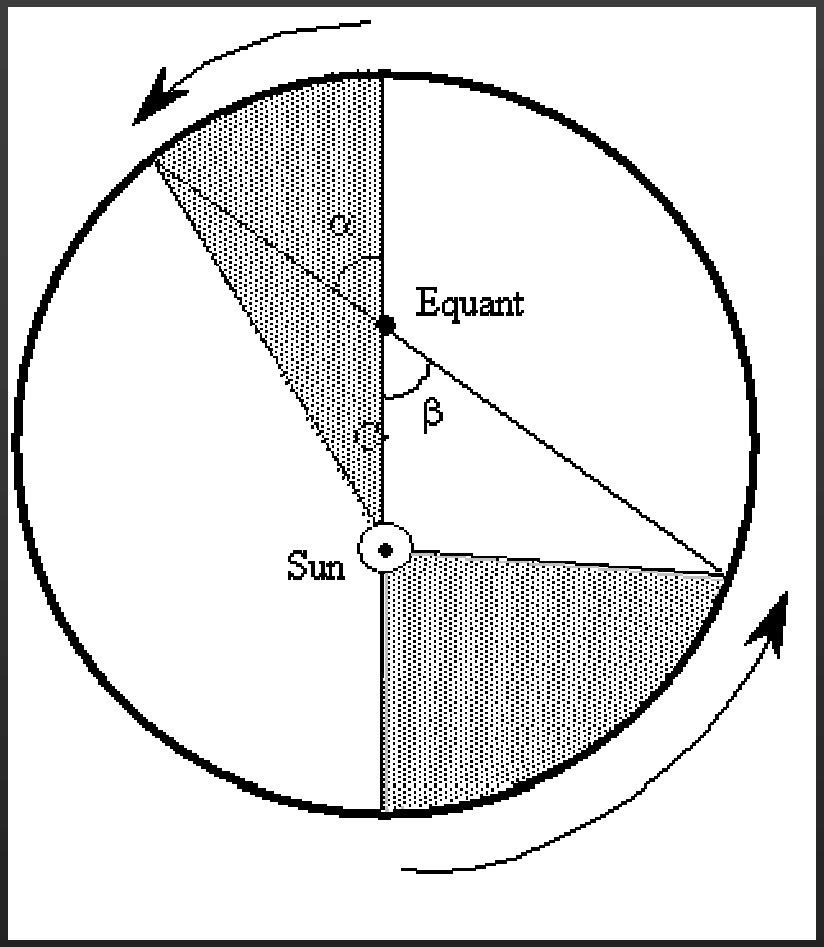
(Conic sections described by Apollonius of Perga in 200 BC)

Speed of the Planets: Kepler's 2nd Law



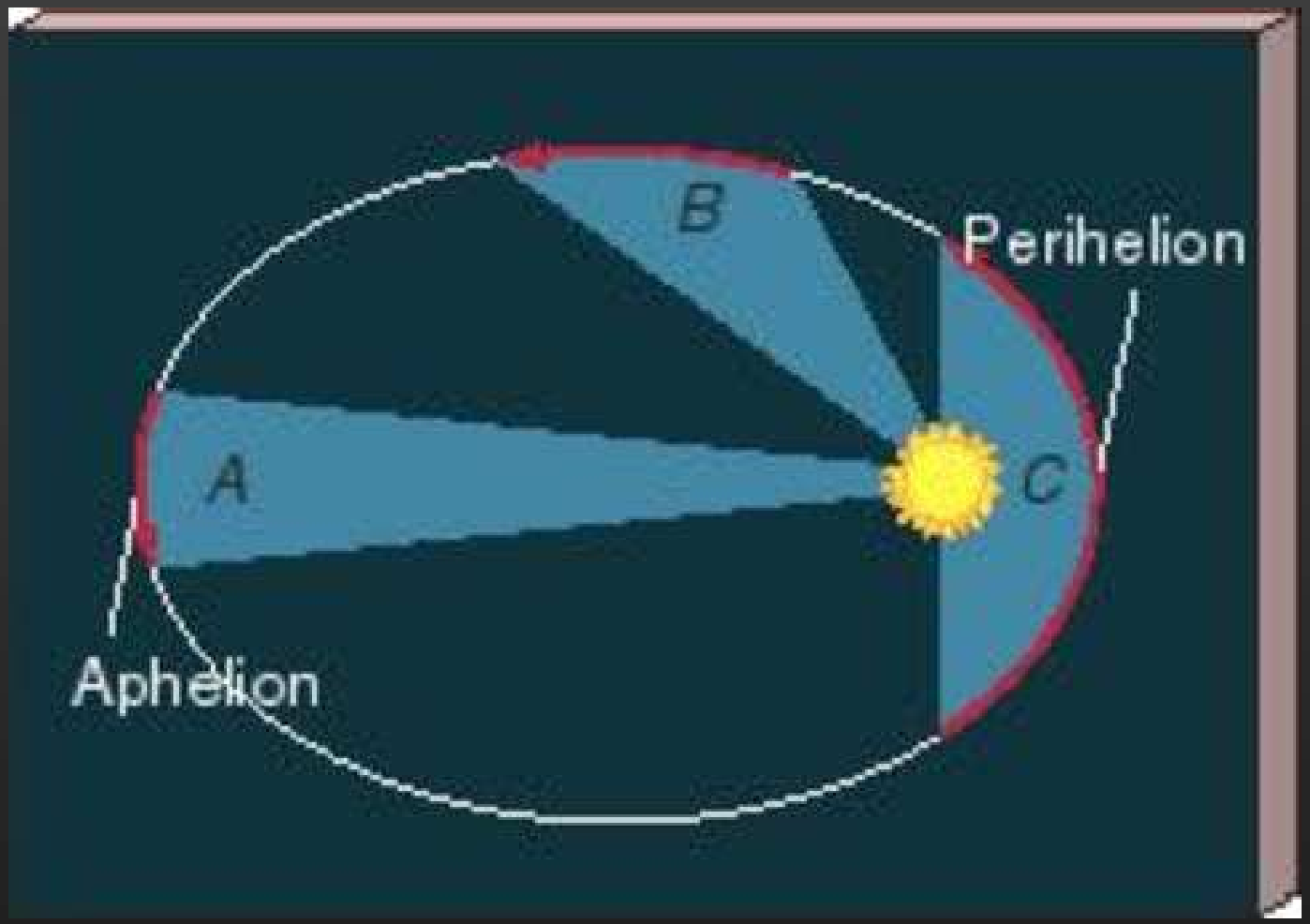
- Start with Sun-centered version of Ptolemy's equant!

Speed of the Planets: Kepler's 2nd Law



- Kepler realizes: Pseudo-equant is almost equivalent to "equal area in equal times" as seen from Sun!

Speed of the Planets: Kepler's 2nd Law



A=B=C

- 2nd Law: A line drawn from the Sun to a planet sweeps out equal areas in equal times!

Finally solving the Problem of the Planets

- One unified framework valid for *all* planets!
  - No ad-hoc fixes allowed!
- For each planet, 2 free quantities (parameters) to choose: semi-major axis a, and eccentricity e
- It could not have been done without Tycho's data!

Coup-d’Etat in Prague (1611)

- Emperor Rudolph deposed by his brother

Rudolph II

Matthias

- Kepler has to leave Prague

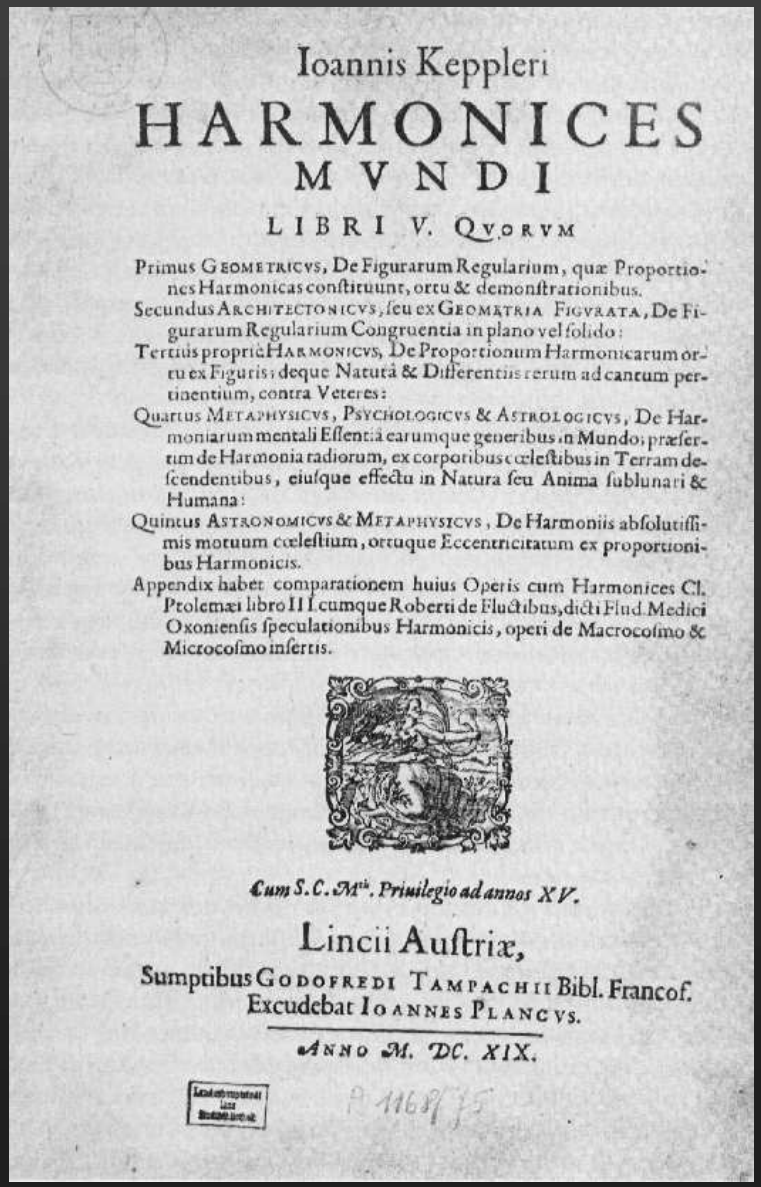
Move to Linz (Upper Austria)

Mathematician in Linz (1612-28)

Linz um 1620

- Teacher at Protestant High School
- Upper-Austrian estate mathematician: horoscopes

The Harmony of the Worlds



Ioannis Keppleri

HARMONICES MVNDI

LIBRI V. QVORVM

Primus GEOMETRICVS, De Figurarum Regularium, quæ Proportiones Harmonicas constituunt, ortu & demonstrationibus.

Secundus ARCHITECTONICVS, seu ex GEOMETRIA FIGVRATA, De Figurarum Regularium Congruentia in plano vel solido:

Tertius propriè HARMONICVS, De Proportionum Harmonicarum ortu ex Figuris; deque Naturâ & Differentiis rerum ad cantum pertinentium, contra Veteres:

Quartus METAPHYSICVS, PSYCHOLOGICVS & ASTROLOGICVS, De Harmoniarum mentali Essentiâ earumque generibus in Mundo; præsertim de Harmonia radiorum, ex corporibus cœlestibus in Terram descendentibus, eiusque effectu in Natura seu Anima sublunari & Humana:

Quintus ASTRONOMICVS & METAPHYSICVS, De Harmoniis absolutissimis motuum cœlestium, ortuque Eccentricitatum ex proportionibus Harmonicis.

Appendix habet comparationem huius Operis cum Harmonices Cl. Ptolemæi libro III. cumque Roberti de Fluctibus, dicti Flud. Medici Oxoniensis speculationibus Harmonicis, operi de Macrocosmo & Microcosmo insertis.

Cum S. C. M^tis. Priuilegio ad annos XV.

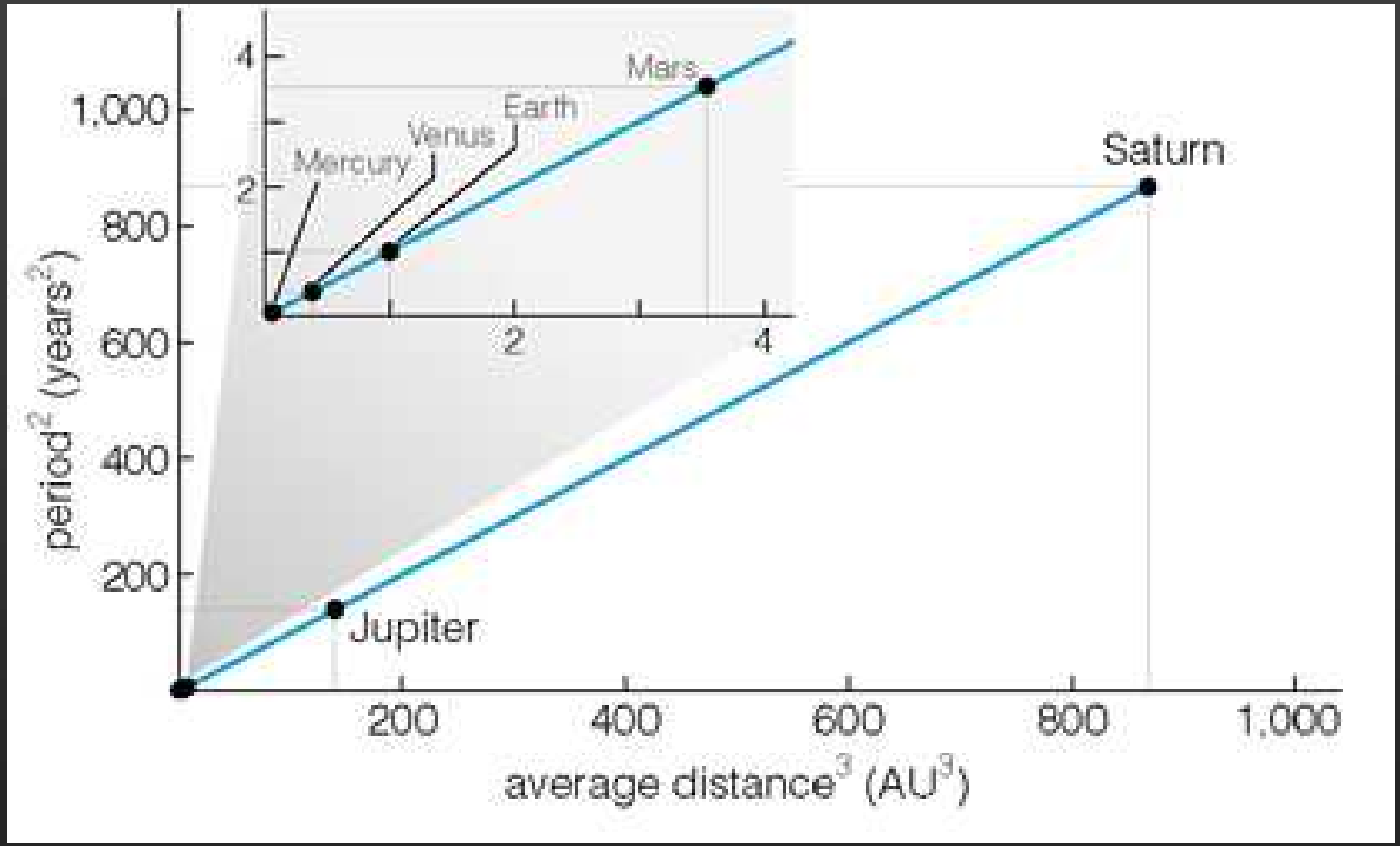
Lincii Austriæ,

Sumptibus GODOFREDI TAMPACHII Bibl. Francof.
Excudebat IOANNES PLANCVS.

ANNO M. DC. XIX.

- *Harmonices Mundi* (Harmony of the Worlds, 1619)
- Kepler's 3rd Law:
  - $P^2=a^3$
- full of mystical speculation

The Harmony of the Worlds



- Kepler's 3rd Law:
  - $P^2=a^3$

The Harmony of the Worlds

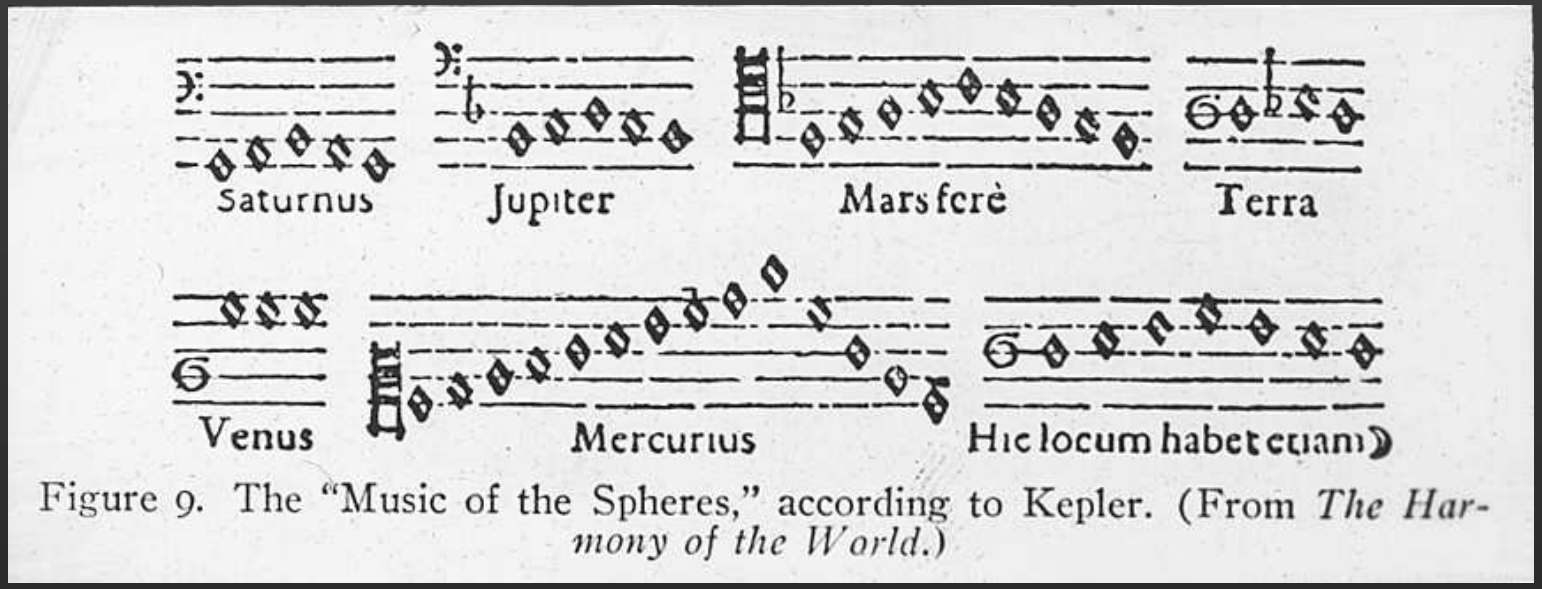


Figure 9. The "Music of the Spheres," according to Kepler. (From *The Harmony of the World.*)

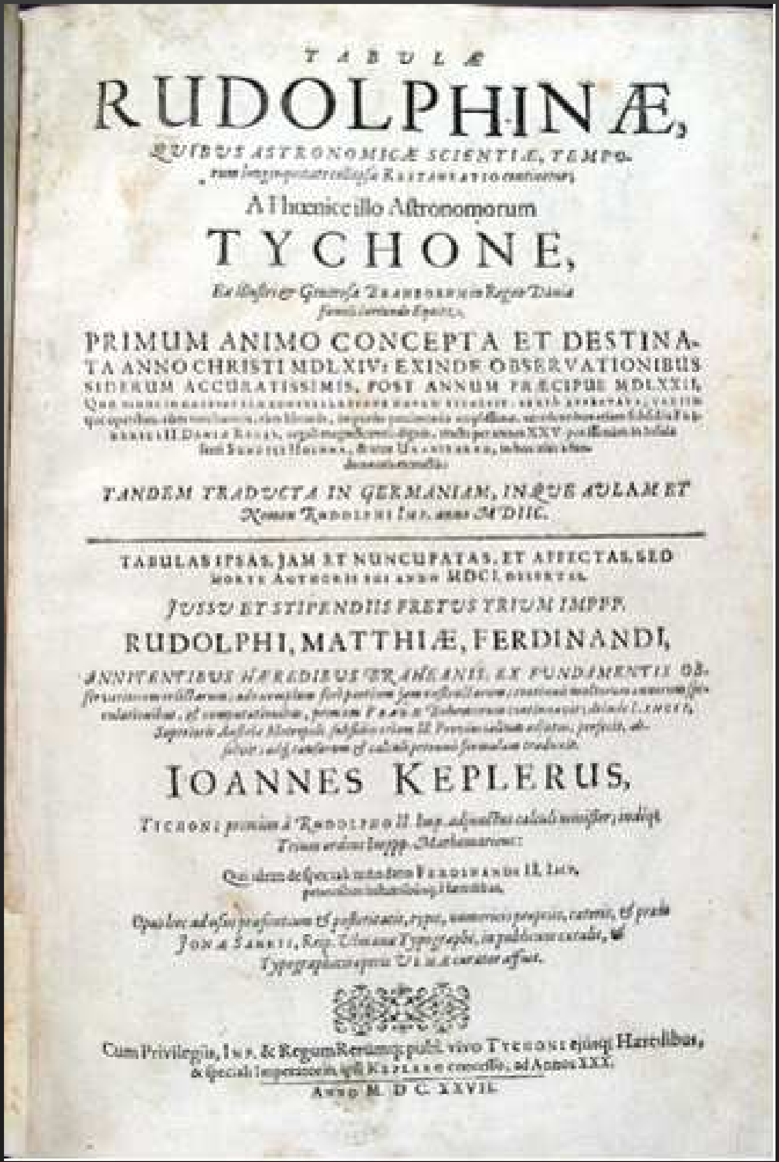
- The Music of the Spheres
- recall: Pythagoras

Rudolphine Tables (Tabulae Rudolphinae)


PRVTENI
CÆTABV
LÆ COE
LESTIVM
MOTVVM.
AVTORE ERASMO REIN
holdo Saluelden.
Cum gratia & priuilegio Cæsareæ & Regiæ Maiestatis.
TVBINGAE PER VLRICVM
Morhardum. Anno M. D. LI.

- improve Reinhold's old (1551) *Prutenic Tables*
- based on Copernicus' *De Revolutionibus*
- limited accuracy in light of Tycho's observations
- Kepler has promised Tycho on deathbed to complete this

Rudolphine Tables (Tabulae Rudolphinae)


TABULÆ

RUDOLPHINÆ,

QUIBUS ASTRONOMICÆ SCIENTIÆ, TEMPO-

TYCHONE,

PRIMUM ANIMO CONCEPTA ET DESTINA-
TA ANNO CHRISTI MDLXIV: EXINDE OBSERVATIONIBUS
SIDERUM ACCURATISSIMIS, POST ANNUM PRÆCIPUE MDLXXII,

TANDEM TRADUCTA IN GERMANIAM, INQUE AULAM ET

TABULAS IPSAS, JAM ET NUNCUPATAS, ET AFFECTAS, SED

JUSSU ET STIPENDIIS FRETUS TRIUM IMPPP.

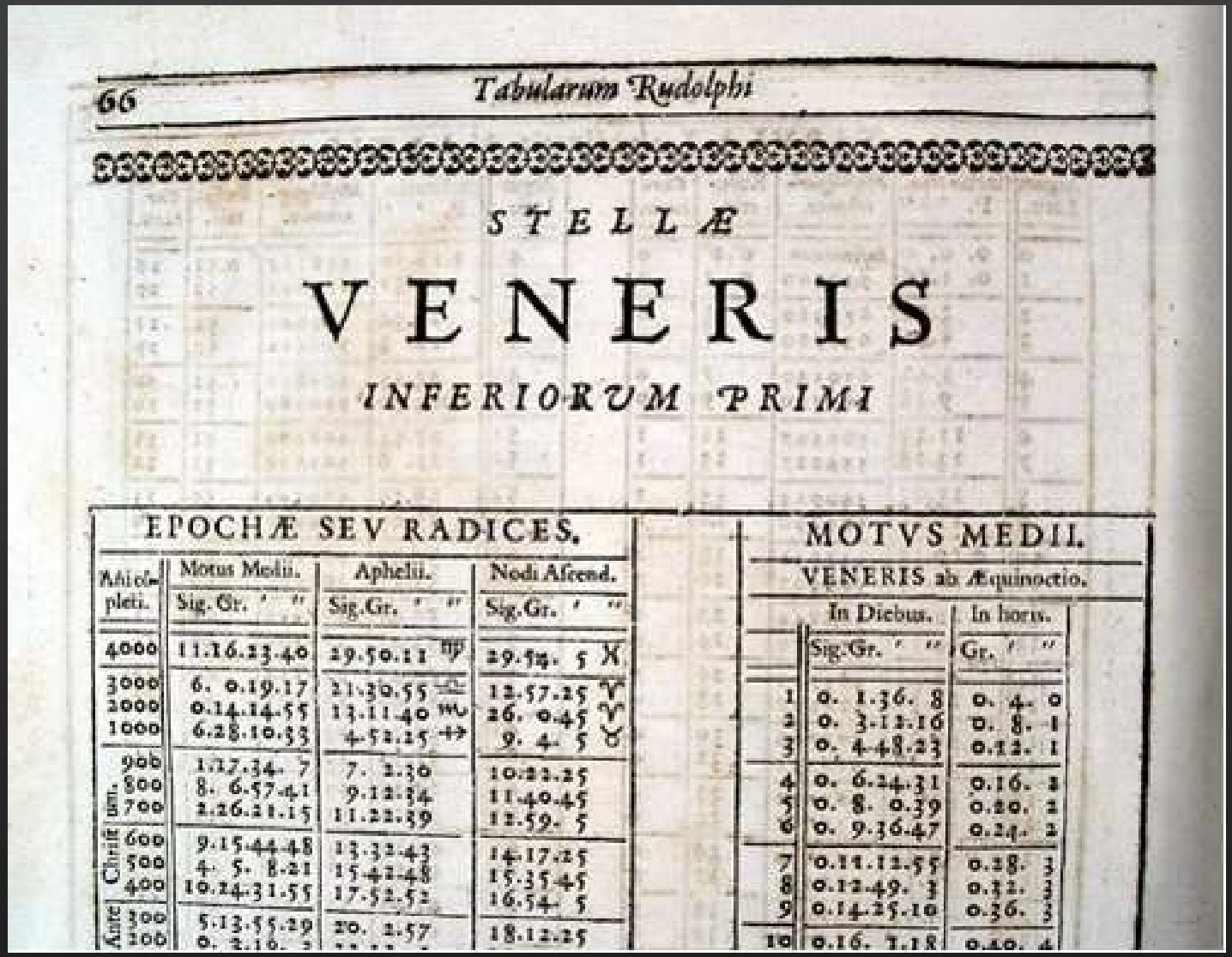
RUDOLPHI, MATTHIÆ, FERDINANDI,

IOANNES KEPLERUS,

ANNO M. DC. XXVII.

- *Tabulae Rudolphinae* (1627)
- based on Kepler's new laws of planetary motion
- unprecedented accuracy (after all: Kepler's is the correct model)
- Astronomers adopt tables first, before the theoretical works

Rudolphine Tables



66 Tabularum Rudolphi

STELLÆ

VENERIS

INFERIORUM PRIMI

EPOCHÆ SEV RADICES.

Anni completi.	Motus Medii. Sig. Gr. ′ ″	Aphelii. Sig. Gr. ′ ″	Nodi Ascend. Sig. Gr. ′ ″
4000	11.16.23.40	29.50.11 ♍	29.14. 5 ♓
3000	6. 0.19.17	21.30.55 ♎	12.57.25 ♈
2000	0.14.14.55	13.11.40 ♏	26. 0.45 ♈
1000	6.28.10.33	4.52.25 ♐	9. 4. 5 ♉
Christi. 900	1.17.34. 7	7. 2.30	10.22.25
800	8. 6.57.41	9.12.34	11.40.45
700	2.26.21.15	11.22.39	12.59. 5
600	9.15.44.48	13.32.43	14.17.25
500	4. 5. 8.21	15.42.48	15.35.45
400	10.24.31.55	17.52.52	16.54. 5
Ante 300	5.13.55.29	20. 2.57	18.12.25
200	0. 3.18. 3		

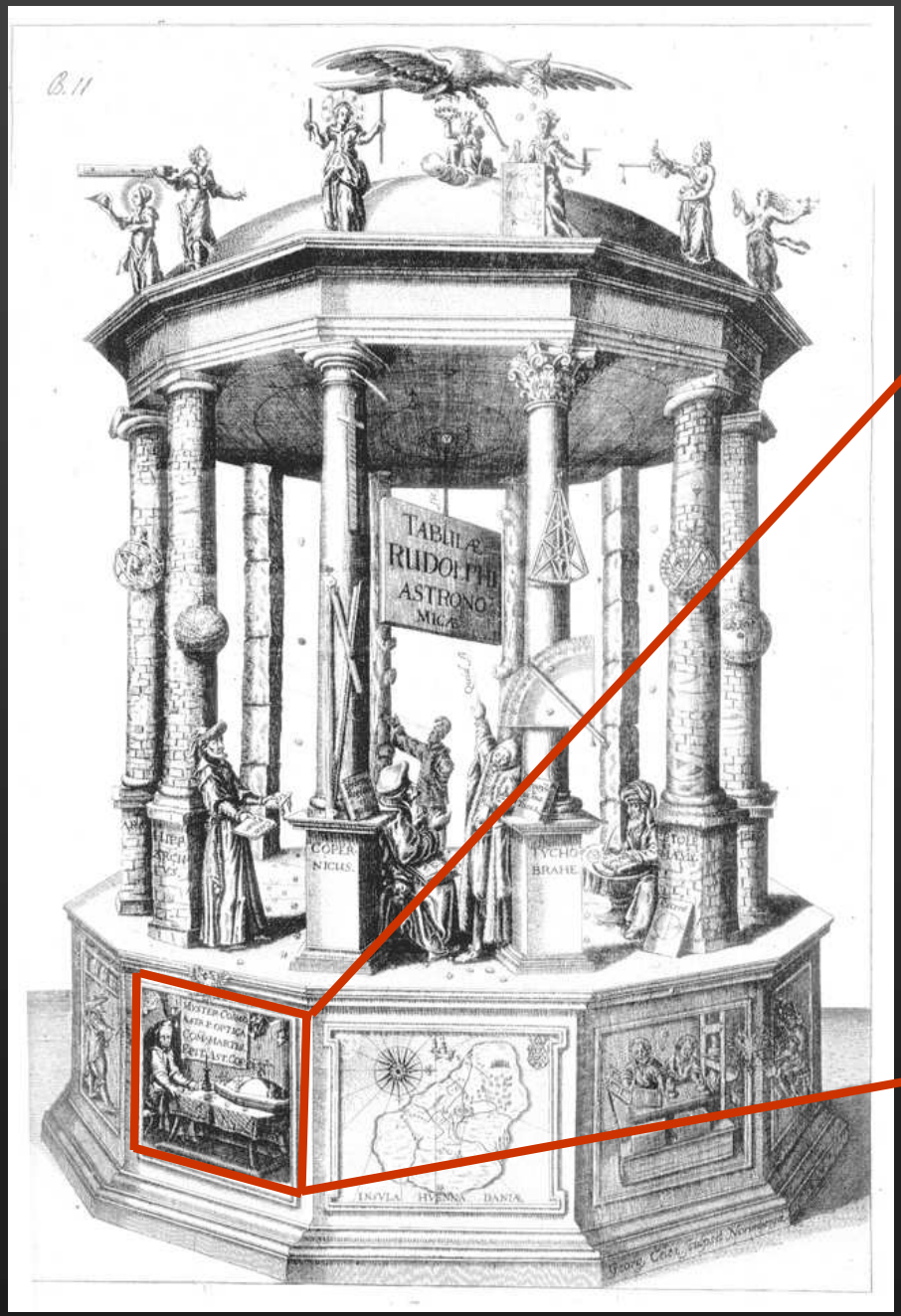
MOTVS MEDII.

VENERIS ab Æquinoctio.

	In Diebus. Sig. Gr. ′ ″	In horis. Gr. ′ ″
1	0. 1.36. 8	0. 4. 0
2	0. 3.12.16	0. 8. 1
3	0. 4.48.23	0.12. 1
4	0. 6.24.31	0.16. 2
5	0. 8. 0.39	0.20. 2
6	0. 9.36.47	0.24. 2
7	0.11.12.55	0.28. 3
8	0.12.49. 3	0.32. 3
9	0.14.25.10	0.36. 3
10	0.16. 1.18	0.40. 4

- Tables: non-glamorous, but very useful!

Rudolphine Tables: The Frontispiece



- Allegory of Astronomy

Witchcraft Trial of Kepler's Mother (1620-21)

"Water Trial"

- Kepler (successfully) defended his old mother

Kepler: Pact with the Devil (1628-30)

Wallenstein, Supreme Commander of Imperial Troops In Thirty Years War

- Entered the employ of generalissimo Wallenstein
- Wallenstein was firm believer in astrology
- Moved to Sagan

Journey's End: Death in Regensburg (1630)

Kepler’s Epitaph:

“I measured the skies, now the shadows I measure. Skybound was the mind, eartbound the body rests”

Kepler's role in the Scientific Revolution

Newton (1642-1727)
- dynamics
- law of gravity

"Standing on the shoulders of giants"

Kepler (1571-1630)
- celestial motion
- 3rd Law

Galileo (1564-1642)
- laws of free-fall
- principle of inertia

Tycho/Kepler (part 2): Johannes Kepler

- Johannes Kepler:
  - finally solves the problem of the planets
  - break free from the old dogma of uniform circular motion
  - completes Copernican Revolution

- Kepler's Laws of Planetary Motion
  - 1st Law: Planets move in ellipses with the Sun in one focus
  - 2nd Law: A line from the Sun to a planet sweeps over equal areas in equal time ("Law of Areas")
  - 3rd Law: $P^2 = a^3$

- Kepler calculates *Rudolphine Tables*
  - New standard of precision