

Astronomy 350L (Spring 2005)



# The History and Philosophy of Astronomy

(Lecture 9: Kepler II)

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# 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**

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(Kepler's nativity)

Kepler: one of the last scientific astronomers!
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
 Orbst Bartigels Skolifficial be deviation of Mars!

#### The New Astronomy: The Orbits of the Planets

ASTRONOMIA NOVA AITIOAOFHTOE, SEV PHYSICA COELESTIS, tradita commentariis DE MOTIBVS STELLÆ M A R T I S, Ex obfervationibus G. V. TTCHONIS BRAHE:

Juffu & fumptibus R V D O L P H I II. R O M A N O R V M IMPERATORIS &c:

> Plurium annorum pertinaci studio elaborata Pragæ,

A St. Ct. M. \* St. Mathematico JOANNE KEPLERO,

Cumejusdem C<sup>4</sup>. M.<sup>14</sup> privilegio speciali Анно æræ Dionysianæ clo loc 1x.  Astronomia Nova (New Astronomy, 1609)

Kepler's 1<sup>st</sup> and 2<sup>nd</sup> 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 1<sup>st</sup> Law**



 1<sup>st</sup> Law: Planets move in ellipses with the Sun in one focus!

#### **Orbit of the Planets: Kepler's 1<sup>st</sup> 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 2<sup>nd</sup> Law



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

#### Speed of the Planets: Kepler's 2<sup>nd</sup> Law



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

#### Speed of the Planets: Kepler's 2<sup>nd</sup> Law



 2<sup>nd</sup> 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)



Teacher at Protestant High School

• Upper-Austrian estate mathematician: horoscopes

# The Harmony of the Worlds

#### Ioannis Keppleri HARMONICES MVNDI

#### LIBRI V. QV.ORVM

Primus GEOMETRICVS, De Figurarum Regularium, quæ Proportiones Harmonicas confituunt, ortu & demonfirationibus.

- Secundus Architectonicos, feu ex Geomatria Figurata, De Figurarum Regularium Congruentia in plano vel folido:
- Tertuis proprie HARMONICVS, De Proportionum Harmonicarum orru ex Figuris: deque Natură & Differentiis rerum ad cantum pertinentium, contra Veteres:
- Quartus METAPHYSICVS, PSYCHOLOGICVS & ASTROLOGICVS, De Harmoniarum mentali Effenti a carunque generibus in Mundo: præfertum de Harmonia tadiorum, ex corporibus cœleftibus in Terram defeendentibus, eiulque effectu in Natura feu Anima fublunari & Humana:
- Quintus ASTRONOMICVS & METAPHYSICVS, De Harmoniis abfolutifimis moruum cœleftium, ortuque Eccentricitatum ex proportionibus Harmonicis.
- Appendix habet comparationem huius Operis cum Harmonices Cl. Ptolemæi libro II I cumque Roberti de Fluctibus, dicti Flud Medici Oxonieníis fpeculationibus Harmonicis, operi de Macrocofmo & Microcofmo infertis.



Cum S. C. Mth. Prinilegio ad annos XV.

Lincii Auftrix, Sumptibus Godofredi TAMPACHII Bibl. Francof. Excudebat Ioannes Plancys. ANNO M. DC. XIX.

11681 15

# Harmonice Mundi (Harmony of the Worlds, 1619)

• Kepler's 3<sup>rd</sup> Law:

- 
$$P^2 = a^3$$

# full of mystical speculation

# The Harmony of the Worlds



# The Harmony of the Worlds



#### The Music of the Spheres

• recall: Pythagoras

# Rudolphine Tables (Tabulae Rudolphinae)



- 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)

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TABULE

disease model

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#### IOANNES KEPLERUS,

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Cum Privilegiis, 1 s.s. & Regum Rerump publi vivo Trenos rejusti Harelibus, & épecial imperatoria (pli Kazasa e concello, ad Annos XXX. Asiso M. D.C. 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**



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 - 3<sup>rd</sup> Law

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

# Kepler (part 2)

# • 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

- 1<sup>st</sup> Law: Planets move in ellipses with the Sun in one focus
- 2<sup>nd</sup> Law: A line from the Sun to a planet sweeps over equal areas in equal time ("Law of Areas")
- $3^{rd}$  Law:  $P^2 = a^3$

# • Kepler calculates Rudolphine Tables

- New standard of precision