Astrophysik I

Norbert Przybilla

Wintersemester 2014/2015

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Organisatorisches

Astrophysik an der Uni Innsbruck

Bachelor, 5. Semester:
- Wahlmodul Astrophysik 1
- Wahlmodul: diverse Möglichkeiten, z.B. Laborpraktikum Astrophysik

Bachelor, 6. Semester:
- Wahlmodul: diverse Möglichkeiten, Bachelorarbeit

Master, 1. Semester:
- Pflichtmodul: Grundkonzepte der Forschung: Astro- und Teilchenphysik
- Wahlmodul: Teleskoppraktikum

Master, 2. Semester:
- Wahlmodule: z.B. Astrophysik 2

Master, 3./4. Semester:
- Wahlmodule: z.B. Forschungspraktikum Astrophysik, Masterarbeit

PhD Thesis

Astrophysik 1

Vorlesung: 3 h 3 ECTS
Di. 12:30 – 13:45 HS E
Do. 16:15 – 17:15 HS G

Proseminar: 1 h 2 ECTS
Gruppe 0: Do. 13:00 – 13:45 HS D Markus Haider
Gruppe 1: Do. 14:15 – 15:00 HS D Markus Haider
Gruppe 2: Do. 15:15 – 16:00 HS D Miguel Urbaneja (engl.)

Klausur (Vorlesung): 20.01.2015

Klausur (Proseminar): 22.01.2015

Zum Bestehen des Moduls müssen beide Teilprüfungen bestanden werden:
$\geq$50% der Punktezahl je Klausur.

Proseminar: + aktive Teilnahme (Teilnahmepflicht, mind. 1$\times$Vorrechnen)
& Hausarbeiten ($\geq$60% bearbeitet) + Bonussystem für Klausurnote

Bücher

KARTUNNEN, KRÖGER, OJA, POUTANEN & DONNER , 2007, *Fundamental Astronomy*, 5th ed., Heidelberg: Springer, € 64 (hardcover), 510 S.

UNSÖLD & BASCHEK, 2006, *Der neue Kosmos. Einführung in die Astronomie und Astrophysik*, 7. Auflage, Berlin: Springer, € 65 (Hardcover), 577 S.

CARROLL & OSTLIE, 2013, *An Introduction to Modern Astrophysics*, 2nd ed., Pearson Education Limited, € 87 (Softcover), 1478 S.

VOIGT, 2012, *Abriss der Astronomie*, 6. Auflage, Wiley-VCH, € 89 (Softcover), 1170 S.

Themenübersicht

- History of Astronomy
- Telescopes, Instruments & Observational Techniques
- Stars & Exoplanets
- Stellar Structure and Evolution
- Interstellar Matter
- Galaxies and Galactic Structure
- Galaxy Clusters
- Cosmology

History of Astronomy

Stonehenge: 2500 BC; solar observatory?

Disk of Nebra: 1600 BC

first reproduction of the night sky, constellation of Moon and Pleiades measures solstices and equinoxes $\Longrightarrow$ calendar

History

Together with theology, astronomy one of the oldest professions in the world.

Astronomical nomenclature is still strongly influenced by this tradition.

$\Longrightarrow$ appreciation of history of astronomy is required for understanding even of today's astronomy. Many terms used are based on this history, e.g. magnitudes by the greek astronomer Hipparcos ($\sim$150 BC)

Early Cosmology

Composite of images of Mars spaced $\sim$ a week apart – from late July 2005 (bottom right) through February 2006 (top left).

Explain observations:

- daily motions of Sun, Moon, planets & stars from E to W
- much slower motion of Sun & Moon with respect to stars
- occasional retrograde motions of planets (E to W)
- solar and lunar eclipses

Babylon

Babylonian astronomy: Earliest astronomy (flourish $\sim$700 BC) with influence on us:

$\Longrightarrow$ sexagesimal system [360:60:60], 24 h day, 12×30 d year,...

$\Longrightarrow$ Observations of Sun and Moon

$\Longrightarrow$ stellar constellations, 12 signs of zodiac

$\Longrightarrow$ bookkeeping on solar and lunar eclipses, Saros cycle: 18 yr 11 d

$\Longrightarrow$ description of planet movement

$\Longrightarrow$ cataloging stellar positions

Image: Mul.Apin cuneiform tablet (British Museum, BM 86378, 8 cm high), describes rising and setting of constellations through the babylonian calendar. Summarizes astronomical knowledge as of before $\sim$690 BC.

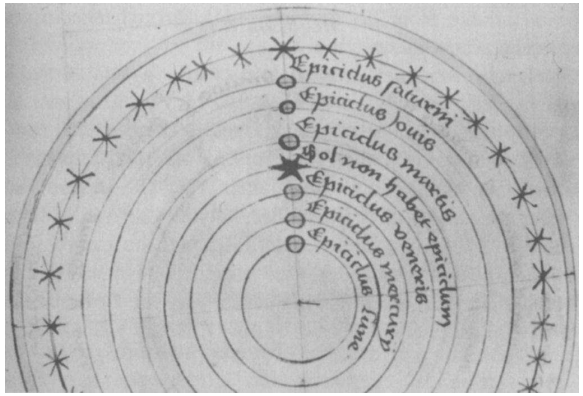
Greek

Atlas Farnese, 2c A.D., Museo Archeologico Nazionale, Napoli

Greek Astronomers: “Mathematicians”
development of the geocentric world model

- Thales (624–547 BC): Earth is flat, surrounded by water. Founder of Natural Philosophy
- Pythagoras (ca. 570–510 BC): Earth is a sphere. “Everything is number” A harmonic universe (music) requires orbital motions in certain ratios of integer numbers (see Kepler: Harmonices mundi)
- Plato (427–347 BC): the circle is the perfect geometric form, uniform circular motion is eternal $\Longrightarrow$ “the hex of circles”
- Eudoxus (408–355 BC): Geocentric, planets affixed to concentric crystalline spheres. 27 spheres to account for non-uniform motions (does not work for Mars and Venus). First real model for planetary motion!

Greek



$\Longrightarrow$ Central philosophy until $\sim$1450AD!

Aristotle (384–322 BC, *de caelo*): Refinement of Eudoxus model: add spheres to ensure correct motions of all planets: $>$50 nested and linked spheres, driven by the outermost sphere.

Celestial objects made out of the fifth substance (quintessence, in addition to earth, air, fire and water).

Greek

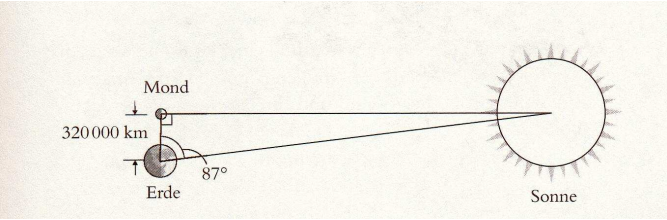
Hipparchus (?? – $\sim$127 BC): First Greek observer:

- Star catalog: 850 stars
- Magnitudes of stars: $0^{\mathrm{m}} \ldots 6^{\mathrm{m}}$
- Parallax of the Moon
- Table of chords (early trigonometry)
- Discovery of precession (shift of the vernal equinox) by comparison with Babylonian star catalog
- Seasons have unequal length
- used geocentric world model of Aristotele to make predictions (Epicycle).

Greek

Ptolemaeus ($\sim$140AD): *Syntaxis* (aka Almagest): Refinement of Aristotelian theory into model useable for computations
$\Longrightarrow$ Ptolemaic System.

Greek



Development of the heliocentric world model: Aristarchus (310–230 BC) determines of the radius of the Sun

1st and last quarter of Moon:

observed $\angle(\text{Moon}, \text{Sun}) = 87°$

$\Longrightarrow$ distances: $D(\text{Sun} - \text{Earth}) = 19 \times D(\text{Moon} - \text{Earth})$

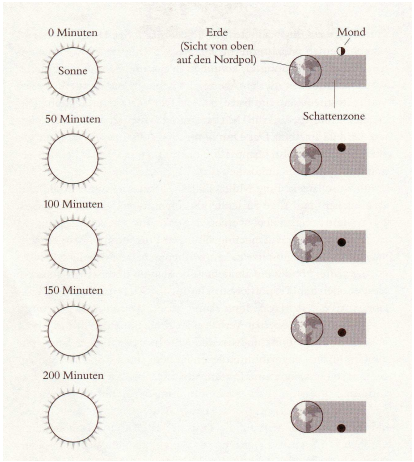
Cassini (1672): Parallax of Mars, which gives $D(\text{Sun} - \text{Earth})$ = 140 Mio. km (using Kepler's 3rd law).

Since angular diameters of Sun and Moon are almost equal:

$$R(\text{Sun}) = 19 \times R(\text{Moon})$$

Greek

Development of the heliocentric world model:
Aristarchus (310–230 BC) radius of the Sun



lunar eclipses:

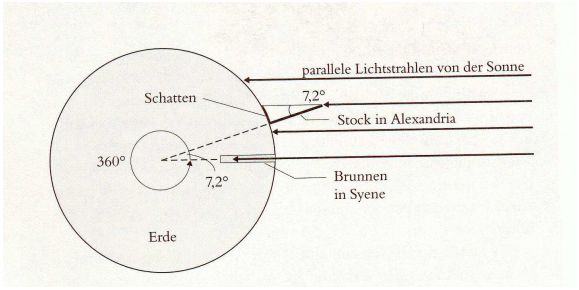
Moon fits into earth shadow twice
(in fact: 3.68 times)

$\Longrightarrow$ Radii: R(Sun)=9.5×R(Earth)

$\Longrightarrow$ common sense: smaller body moves around the larger one!

Heliocentric world model

Greek



Eratosthenes (276–195 BC): measurement of the earth's radius

Idea: measure culmination of the Sun at two places of known distance (N to S) on the same day.

Syene: Sun at zenith, Alexandria: 7.2° away from Zenith

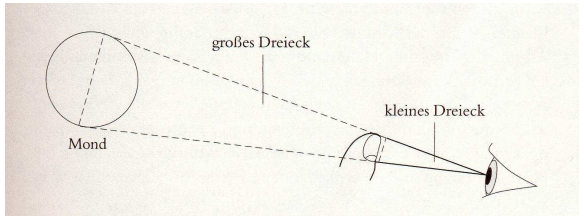
$\Longrightarrow$ Distance between Alexandria and Syene: $d/(2\pi R) = 7.2/360$

Measured: 5000 Stades

Some historians believe that this distance corresponds to ∼820 km, so if true then the radius of the Earth would have been determined to 6264 km

in fact: 6378km; repeated: 1671: Paris-Amiens (J. Picard)

Greek



The distance to the Moon and the Sun:
angular diameter of the Moon equals width of finger as seen from 1 m away
$\Longrightarrow R_{\text{moon}}/d_{\text{moon}} = 1/200$

Lunar occultations: $R_{\text{moon}} = 1/2 R_{\text{earth}}$

$\Longrightarrow R_{\text{earth}}/d_{\text{moon}} = 1/100$

$$d_{\text{moon}} = 100 \times R_{\text{earth}} = 626400\,\text{km}$$

$\Longrightarrow$ distance to the Sun:

$$d_{\text{sun}} = 19 \times d_{\text{moon}} = 11.9\,\text{Mio km}$$

Renaissance

Regiomontanus: Johannes Müller from Königsberg (Franconia) (1436–1476):

- Studies at Leipzig (1447) and Vienna (1450): Maths and Astronomy
- *Epytoma Joanis de monte regio in almagesti ptolemei* (1461–1463): translation to latin with much improved maths
- *De triangulis omnimodis* (1462–1464): foundation of modern trigonometry
- *Ephemerides astronomicae ab anno 1475–1506*: most accurate ephemerides
  $\Longrightarrow$ Navigation: Columbus & Vasco da Gama
- Founder of Nuremberg Observatory

Renaissance

Nicolaus Copernicus (1473–1543): Earth centred Ptolemaic system is too complicated, a Sun-centred system is more elegant.

Renaissance

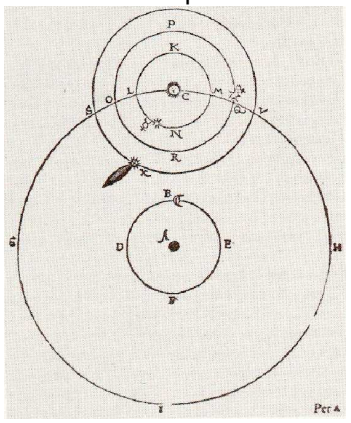
Nicolaus Copernicus (1473–1543): Earth centred Ptolemaic system is too complicated, a Sun-centred system is more elegant:

De revolutionibus orbium coelestium: “In no other way do we perceive the clear harmonious linkage between the motions of the planets and the sizes of their orbs.”

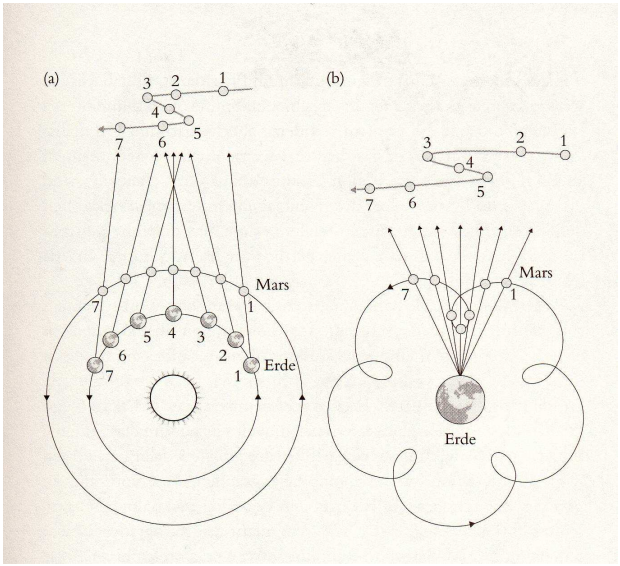
Copernican principle: The Earth is not at the center of the universe.

Renaissance

Tycho Brahe (1546–1601): Visual planetary positions of highest precision reveal flaws in Ptolemaic positions.



Renaissance



Retrograde motion: heliocentric vs geocentric model

Renaissance

Johannes Kepler (1571–1630): Planets orbit on ellipses around Sun, not on circles, laws of motion.

Galileo Galilei (1564–1642): Telescopic observations, discovery of four moons of Jupiter

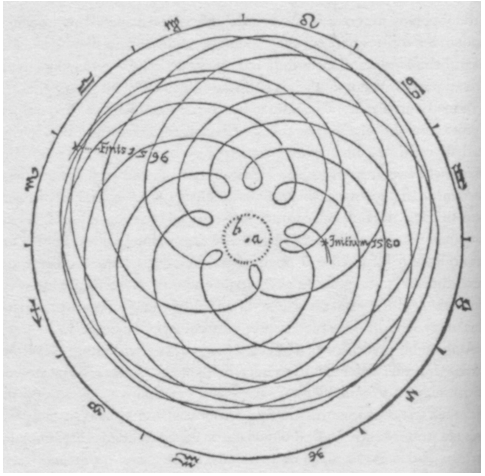
Renaissance

Johannes Kepler (1571–1630):

- born 27.12.1571, Weil der Stadt
- Studies in Tübingen with Maestlin
- 1594–1600: Graz
- 1596: Mysterium Cosmographicum
- 1600–1612: Prag, assistant of Tycho Brahe, then Mathematician of emperor Rudolf II, discovered Supernova of 1604,...

1609: Astronomia Nova

Renaissance

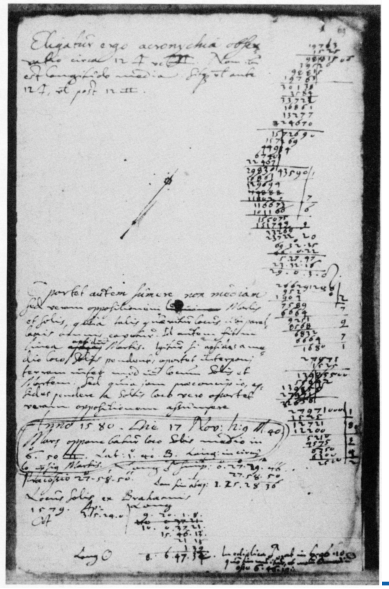


Astronomia Nova, Kapitel 1: motion of Mars in the epicycle theory between 1560 and 1596

Astronomia nova (Prag, 1609)

Critic of the epicycle theory: “panis quadragesimalis” (Osterbrezel)
$\Longrightarrow$ Inelegant!

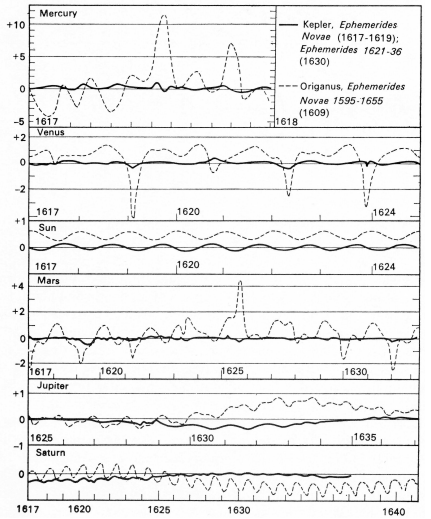
Renaissance



Result of Kepler's investigations:
The Keplerian laws:

1. Planets move on elliptical orbits, Sun in focus.
   ("Astronomia Nova", 1609)
2. Motion is not uniform, planet moves fast when close to the Sun.
   ("Astronomia Nova", 1609)
3. Third law comes 10 years later
   ("Harmonice Mundi", 1619)

Renaissance

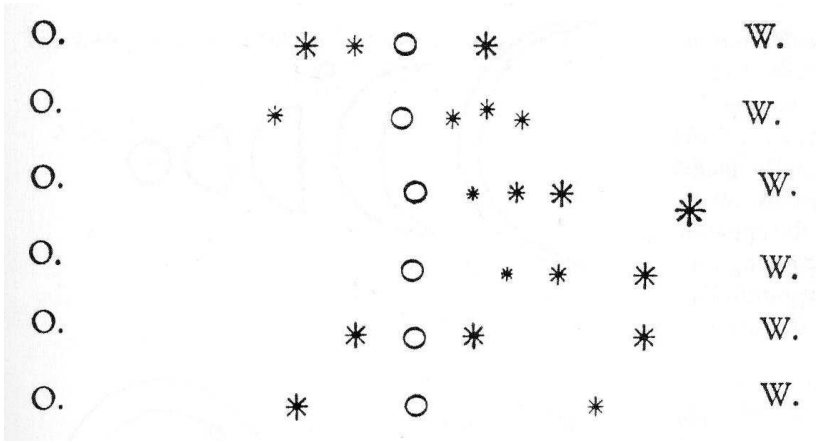


Tabulae Rudolphinae, 1627

Most precise positions of planets ever:
30× smaller errors than before

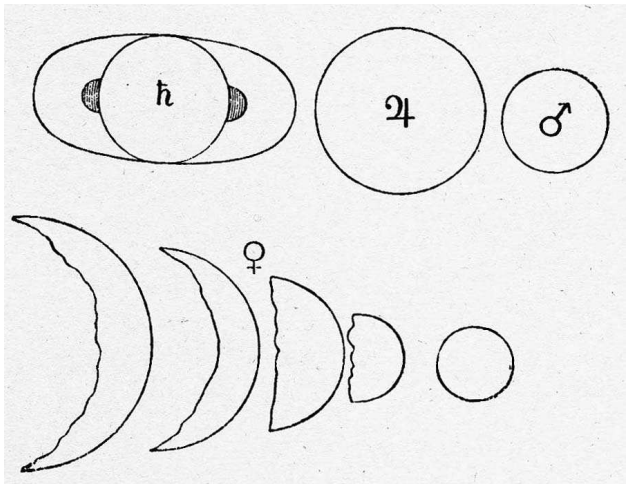
(Gingerich, 1993)

Renaissance



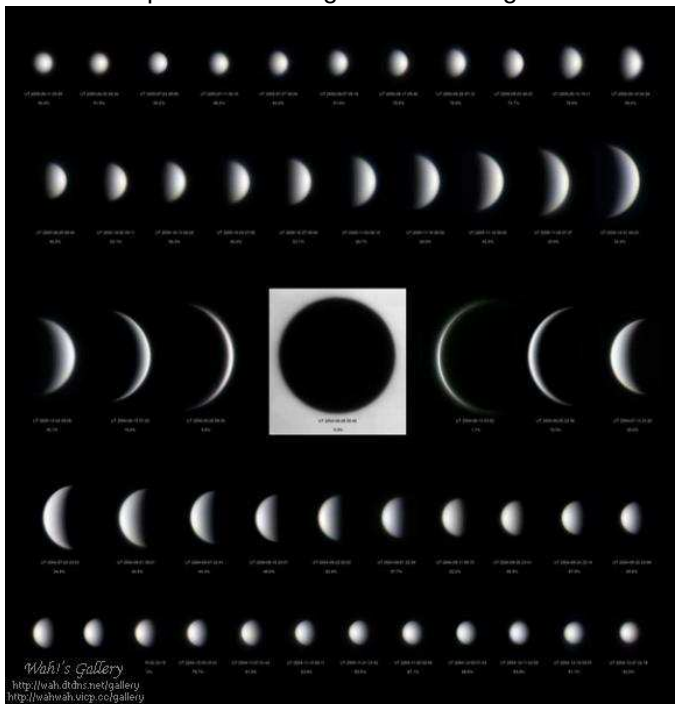
Moons move around Jupiter
($\Longrightarrow$ similar to heliocentric model!)...

Renaissance

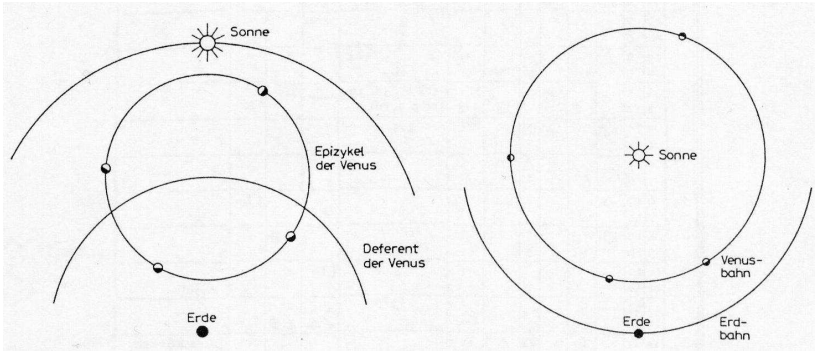


Discovery of phases of Venus (Il Saggiatore, 1623)

Observed phases and angular size changes of Venus

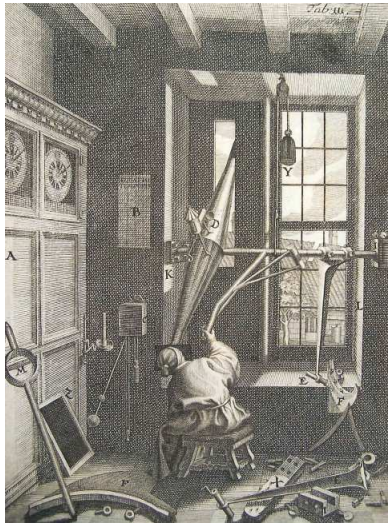


Renaissance



The observed phase changes of Venus can be explained by the heliocentric world model, but also in Tycho´s geocentric.

Rømer



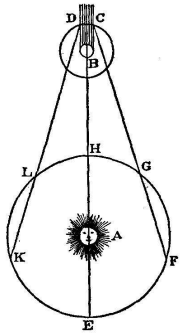


Fig. 70.

Rømer, 1676

Ole Rømer (1644–1710): measurement of the speed of light

Times of occultation of Io shift by up to 20 minutes during the year.

(Peter Horrebouw, Basis astronomiae sive astronomiae machina, Kopenhagen, 1735)

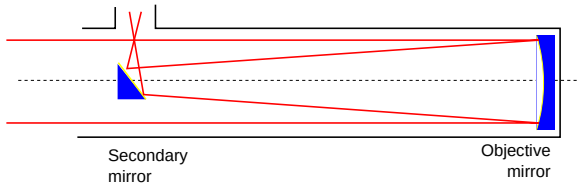
Newton

Isaac Newton (1642–1727): Newton's laws, physical cause for shape of orbits is gravitation
(*De Philosophiae Naturalis Principia Mathematica*, 1687).

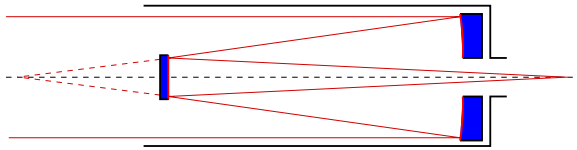
$\Longrightarrow$ Begin of modern physics based astronomy.

Telescopes

Newton telescope



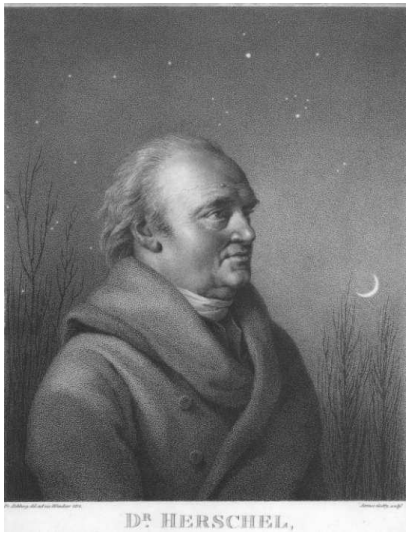
Cassegrain telescope

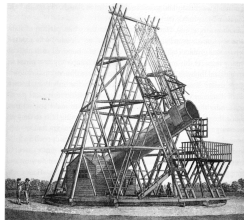


Newton (1668), Gregory (1670), Cassegrain (1672): Mirror telecopes

(mirror made of polished metal [copper/zink alloy])

Herschel

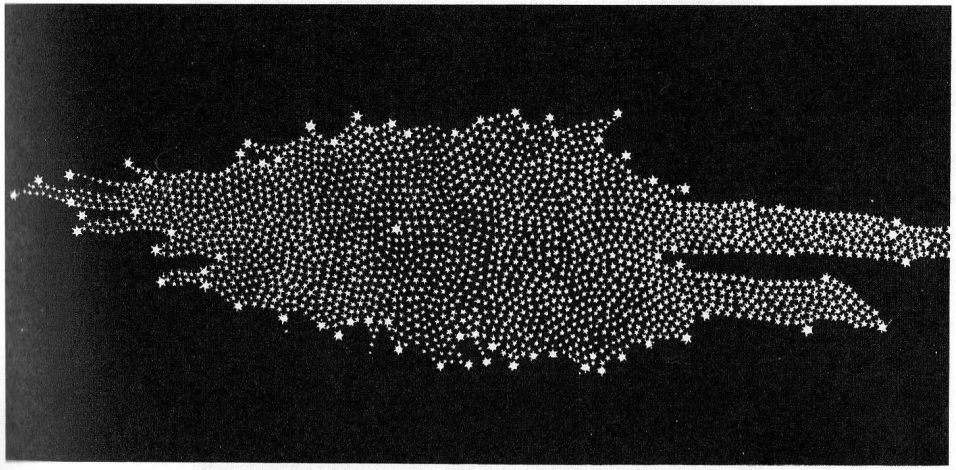




William Herschel (1738–1822):

- 15.11.1738: born. in Hannover, Oboist, emigrated to England 1759
- manufactures great mirror telescopes
- 1781: Discovery of Uranus
- study of Nebulae
- Star counts (with his sister Caroline Herschel),

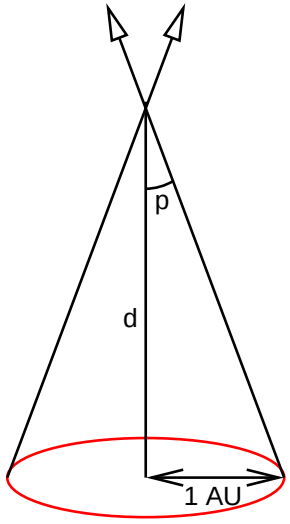
Herschel



Geometry of the Milky Way according to William Herschel (1785)

Sun is close to the centre of the Milky Way

Herschel



$\Longrightarrow$ Wanted: Measurement of a yearly parallax of a star.

Parallax (small angles):

$$p = \frac{1\ \text{AU}}{d}$$

(p measured in radian)

Problem since antiguity: p is small because the stars are so far away.

Bessel

Friedrich Wilhelm Bessel
(1784–1846)

Bessel (1839): first distance measurement of a star

ASTRONOMISCHE NACHRICHTEN.

№. 365. 366.

Bestimmung der Entfernung des 61sten Sterns des Schwans.

Von Herrn Geheimen-Rath und Ritter *Bessel*.

Als es *Bradley* gelungen war, seine Beobachtungen in *Kew* und *Wanstead*, welche die Entdeckungen der Aberration und Nutation herbeiführten, durch diese allein genügend zu erklären, ohne dazu der Annahme einer jährlichen Parallaxe der beob- ist nicht zu bezweifeln; allein wenn eine Untersuchung über die jährliche Parallaxe eines Fixsterns unternommen werden soll, so sind sie dennoch die einzigen, welche seine Wahl leiten können.

61 Cyg: Parallax 0.3″
$\Longrightarrow$ distance 11 light years

The great debate

Whirlpool nebula
(Lord Rosse, ≈ 1850)

19th century: Astronomy evolves into a modern natural science:

- precise stellar position (“Durchmusterungen”=surveys)
- Photography
- Spectroscopy (Astro*physics*)

The nature of the nebulae?

The great debate: 26.4.1920

protoplanetary nebulae

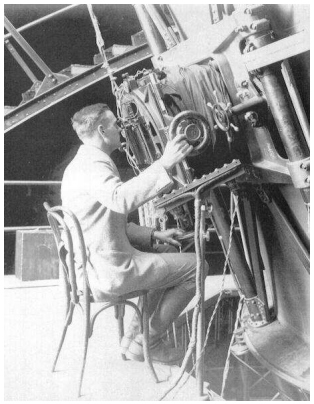
or

island universe (“Welteninsel”):

Harlow Shapley vs. Heber Curtis

Hubble

Mount Wilson 2,5m Teleskop



Edwin Hubble, 1922