TYCHO BRAHE E A ORDEM DOS CÉUS

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Tycho Brahe e ordem dos céus

Sumário

- Introdução
- Dados biográficos
- Paralaxe
- Instrumentos
- Sistema do Mundo (cosmologia)
- Bibliografia

Introdução

- “Tycho Brahe, o Medidor dos Céus”
- “Tycho Brahe e a arquitetura do universo”
- “Tycho Brahe, o Engenheiro do Cosmos”
- “Tycho Brahe e a Estrutura Sideral”
- “…”

CONEXÕES

Medidas de Tycho → Leis de Kepler → Física de Galileu

Gravitação universal de Newton

Tycho Brahe (1546-1601)

Johannes Kepler (1571-1630)

Galileu Galilei (1564-1642)

Isaac Newton (1642-1727)

Dados Biográficos

* 14/12/1546 – Knudstrup, Dinamarca
† 24/10/1601 – Praga, Boêmia, atual Rep. Tcheca

- 19/04/1559 – Direito, Univ. de Copenhague

→ **ECLIPSE de 1560!!!**
- previsibilidade!
- … mas com erro!

- 1566 – perde parte do nariz num duelo
- 1572 – dois fatos:
  - **conhece Kirsten Jorgensdatter**
  - **supernova**

- Cedo aprendeu que boas observações requerem bons instrumentos
- Telescópios: a partir de 1609
- Relógios: de pêndulo, por Galileu e Christian Huygens (1629-1695). De corda (mola) já existiam desde ~ 1530
- Tycho trabalhou nas observações a olho nu de 1570-1601
- Tycho: costume de colocar o erro ao lado da medida
- Interesse pela astronomia despertado pelo eclipse solar de 21/08/1560, aos 14 anos incompletos

- 1575 – Rei Frederico, da Dinamarca, lhe oferece a ilha de Hven (hoje Ven, na Suécia)

→ **Castelo de Uraniborg, a Cidade dos Céus!**

- 1576-1597 – Observações em Uraniborg
- Constroi **Esterborg**, anexo a Uraniborg: **Castelo das Estrelas!**

- 1599 – Já em Praga, Johannes Kepler passa a trabalhar como seu assistente

Castelo de Uraniborg, a Cidade dos Céus

Notar a orientação das ruínas da construção segundo os pontos cardeais.

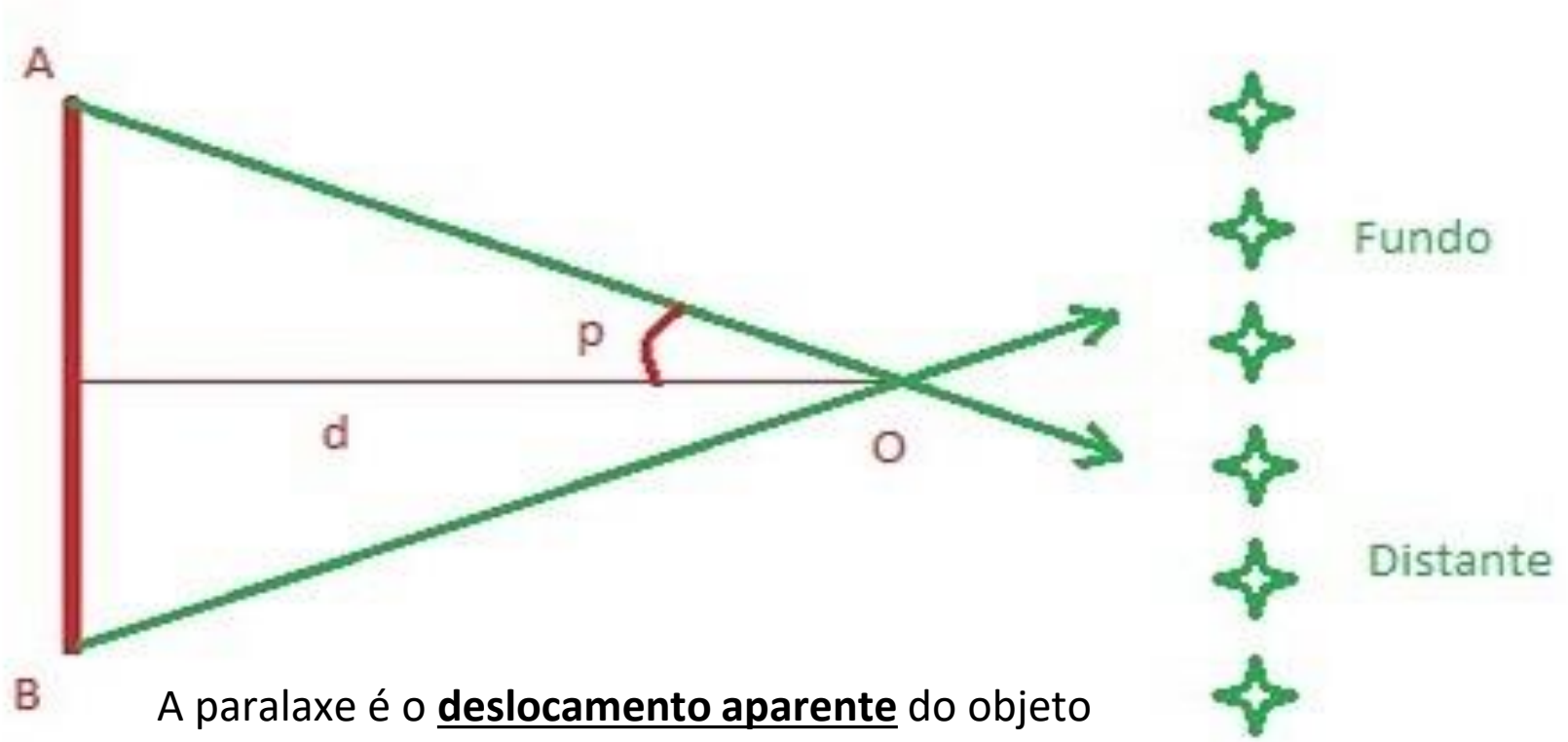
(Google Earth, ilha de Ven na Suécia)

Castelo de Uraniborg, a Cidade dos Céus

Outra vista, com maior aproximação. Notar os sítios dos instrumentos astronômicos.

(Google Earth, ilha de Ven na Suécia)

Paralaxe



A paralaxe é o **deslocamento aparente** do objeto observado, devido **à mudança de posição do observador**

Paralaxe: **tg p = (AB/2)/d,** e para o ângulo p muito pequeno: **tg p ≈ p,** então

→ **p = (AB/2)/d**

- Por que temos dois olhos?

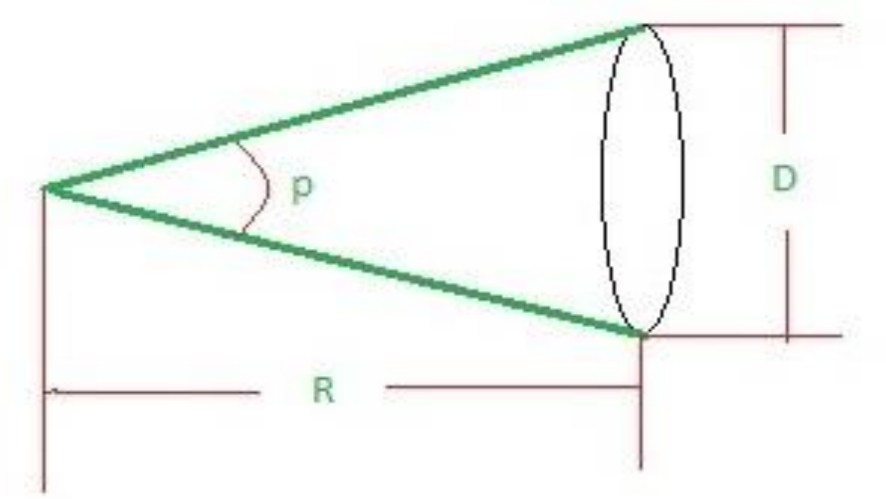
  → **ou um olho + pescoço articulado?**

- Experiência: polegar à distância do braço

  AB ≈ 6 cm; 2 x p ≈ 1,5 polegar

  (Obs.: p não é pequeno)

... E A PROPÓSITO DE DIMENSÕES ANGULARES →



$p_{LUA} = D_{LUA} / R_{TL} = 3{,}48 \times 10^6 \text{ m} / 3{,}82 \times 10^8 \text{ m} =$
$= 0{,}00911 \text{ rad} = 0{,}522^\circ = \underline{\mathbf{31{,}3'}}$

$p_{SOL} = D_{SOL} / R_{TS} = 13{,}92 \times 10^8 \text{ m} / 1{,}50 \times 10^{11} \text{ m} =$
$= 0{,}00928 \text{ rad} = 0{,}532^\circ = \underline{\mathbf{31{,}9'}}$

POLEGAR À DISTÂNCIA DO BRAÇO ≈ 2 cm/60 cm ≈

$0{,}0333 \text{ rad} = 115' \approx \underline{2^\circ} \approx$ **4 LUAS!**

Paralaxe geocêntrica:

DISTÂNCIAS À LUA E AOS PLANETAS

AB = diâmetro da Terra

Paralaxe heliocêntrica:

DISTÂNCIAS ESTELARES

AB = diâmetro da órbita da Terra

- supernova de Tycho (1572): **não detectou paralaxe!**
- 13/11/1577: pela 1ª vez avista um cometa.

Localiza-o **além da órbita de Vênus!**

→ **céus não eram imutáveis como preconizava Aristóteles.**

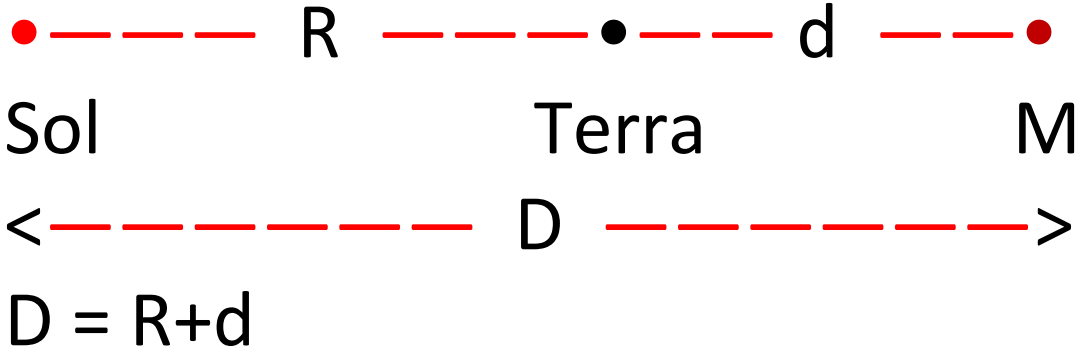
Distância Terra-Sol

Métodos diferentes:

1) 1672: Giovanni Cassini, em Paris

John Flamsteed, em Derby, Inglaterra

ambos mediram a **paralaxe** de Marte, em oposição naquele ano ⇒ **d**



D = R+d

d + lei de Kepler dos períodos implica em

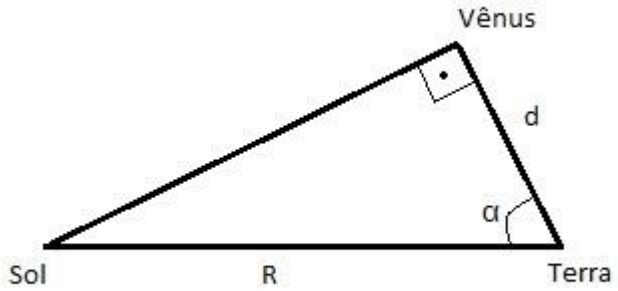
$R \approx 140 \times 10^6$ km

(publicado pelos dois em 1673)

2) ... mas em 1653, Christiaan Huygens...

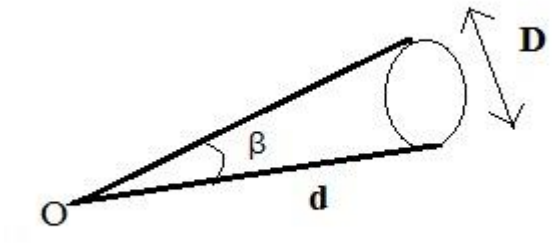
- distância até Vênus
- fases de Vênus

Fase Cheia:



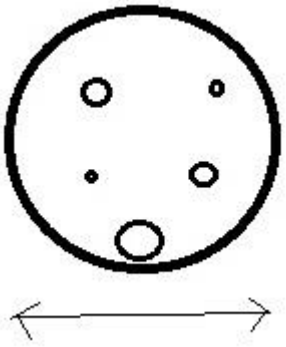
Distância até Vênus:

$$B = \frac{D(\text{Vênus})}{d} = \frac{D(\text{Terra})}{d}$$



baseado em numerologia e misticismo!

A PROPÓSITO: MÉTODO DE HUYGENS PARA MEDIR DISTÂNCIAS ESTELARES



diâmetro aparente do Sol

DISTÂNCIA A SIRIUS: ORIFÍCIO COM 1/28.000 DO SOL

R(Sirius) = 28.000 x R(Sol) =

= 28.000 x 8 minutos-luz = 0,5 ano-luz

PROBLEMA: Sirius é intrinsicamente mais brilhante do que o Sol!

VALOR CORRETO: R(Sirius) = 5,8 anos-luz

Instrumentos

- Projetou e construiu, entre 1570 e sua morte em 1601:

1) QUADRANTES E SEXTANTES
   → altitudes e azimutes
2) ESFERAS ARMILARES
   → ascensões e declinações
3) SEXTANTES ESPECIAIS
   → distâncias angulares entre corpos celestes

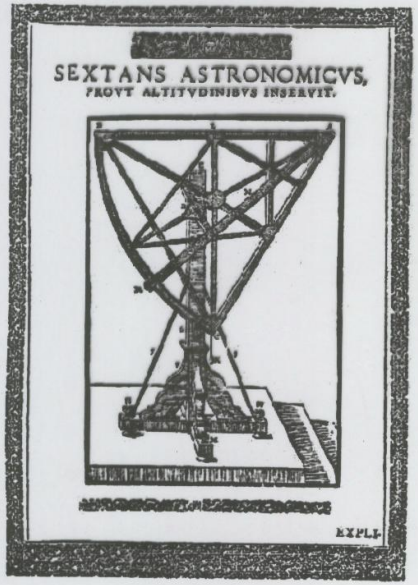
- INSTRUMENTOS GRANDES (~ METRO) PARA AUMENTAR PRECISÃO NAS MEDIDAS ANGULARES

OBRA IMPORTANTE: "ASTRONOMIAE INSTAURATAE MECHANICA" , OU, "INSTRUMENTOS PARA A RESTAURAÇÃO DA ASTRONOMIA"

- descreve 29 instrumentos + detalhes técnicos dos observatórios de URANIBORG e ESTERBORG.
- PRECISÃO FOI MELHORADA de 15' (antes de Tycho) para 2', e as melhores ± 0,5' !

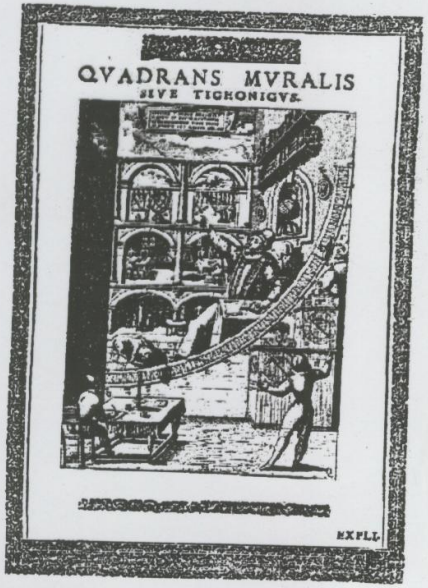
[W.G. Wesley, "The accuracy of Tycho Brahe's instruments", J. Hist. Astron. 9, 42-53 (1978)]

*Mechanica pages 5-8



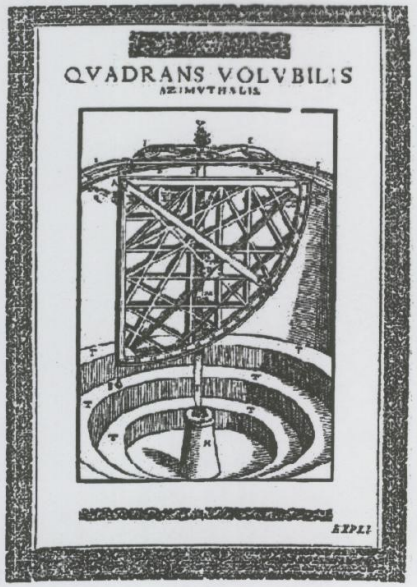
The astronomical sextant for altitudes

Sextants were favourite instruments of Tycho. They were used both to determine altitudes and to measure distances between stars. This is one of three sextants of about the same size that Tycho built. It was placed in the southern larger observatory in Uraniborg. The instrument was probably made of wood, but cleverly covered with brass plating and it looked as if it was made of solid brass. The limb and the sights were also made of brass. The radius was 155 cm. This sextant hung on a pillar and was turnable only in the vertical plane. Thus, only altitudes could be measured with this instrument. When altitudes were to be measured, the instruments upper leg had to be exactly horizontal. To achieve this, a plumb line was used. The instrument was rather light and could be taken apart and remounted in another place.



The great mural quadrant (1582)

This was one of Tycho's most important instruments and, at the same time, probably the most simple to understand. It consisted of a solid brass arc, a quarter of a circle, mounted directly on the wall. It was placed on the west wall in the southwestern room of the castle. The instrument was carefully adjusted to the meridian's plane; the north-south direction. On the arc, there were two sliding sights. In the southern wall, close to the ceiling, there was a little hole with a cylinder of gilt brass. The observer slid the sight until he saw the star in line with the cylinder. If the sun was to be observed, the shadow of the cylinder was caught on the sight. With this instrument, Tycho could determine the meridian altitudes of the heavenly bodies. He could also find out the time of the meridian transit. The instrument had Tycho's famous tranversal system for accurate readings. It could be read to a sixth of a minute, that is ten seconds. Tycho also called the instrument the Tychonian quadrant. The wall behind the instrument was beautifully decorated by famous artists.



The revolving azimuth quadrant
(1586)

This instrument was made partly of steel, partly of brass. The radius was 155 cm. It had an azimuth circle, 230 cm in diameter, mounted directly on the wall. Both altitudes and azimuths could be taken. The instrument was placed in the northeastern crypt of Stjerneborg. It had a scale with the minutes divided into four parts, which allowed readings to an accuracy of fifteen seconds. The instrument was turnable all around the horizon. With this instrument, Tycho very carefully (by means of Polaris) determined the latitude of his observatory. He measured the highest and lowest altitude of the star. From several observations he calculated a mean figure. His latitude differs from the correct one by only fourteen seconds! In the same way, Tycho measured the star in its most easterly and westerly positions and determined the direction of the meridian, the true north direction. The error was less than half a minute.

The great steel quadrant (1588)

With the great mural quadrant, it was possible to measure altitudes only in the meridian. This was not satisfactory. Tycho, therefore, also construc-ted quadrants turnable in the horizontal plane, that made it possible not only to take sights in all directions, but also to determine the direction; the azimuth. The previously described instrument was one of these, and this one is another. This one was the biggest of Tychos quadrants, 194 cm in radius. The azimuth circle on the wall was 350 cm in diameter. The instrument was built of steel but the scale and the sights were of brass. It could be read to an accuracy of ten seconds. The quadrant was circumscribed by a quadrangle in steel which gave a superb stability to the instrument. Tycho said a person could climb on to the instrument and, hanging on to it, be turned around without the instrument being damaged. The instrument was placed in the southwestern crypt of Stjerneborg. The stone steps and the stone pillar in the middle of the crypt still remain and can be seen in the ruins of Stjerneborg.

QUADRANS MURALIS SIVE TICHONICUS

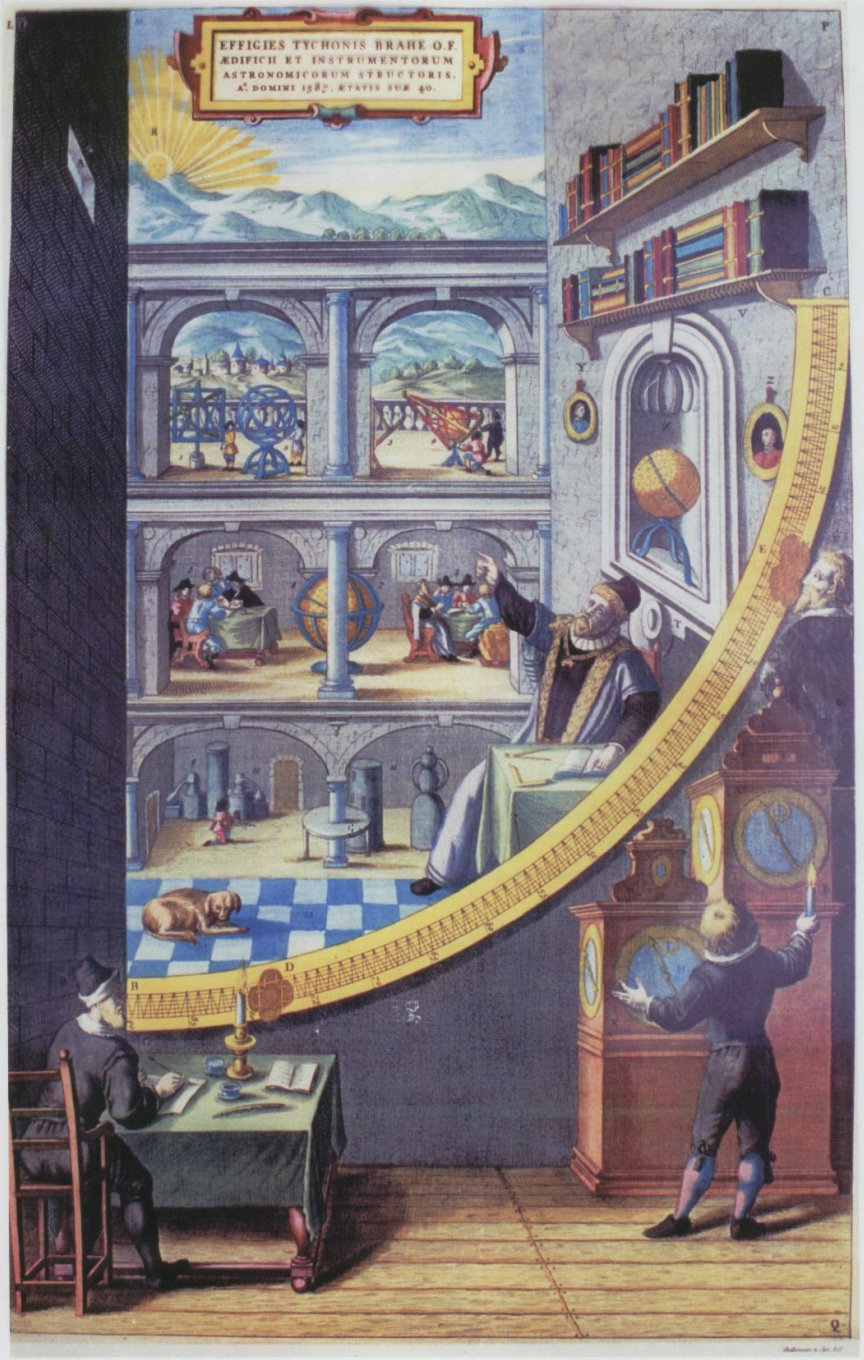
THE MURAL, OR TYCHONIAN, QUADRANT

DESCRIPTION AND USE OF THE INSTRUMENT

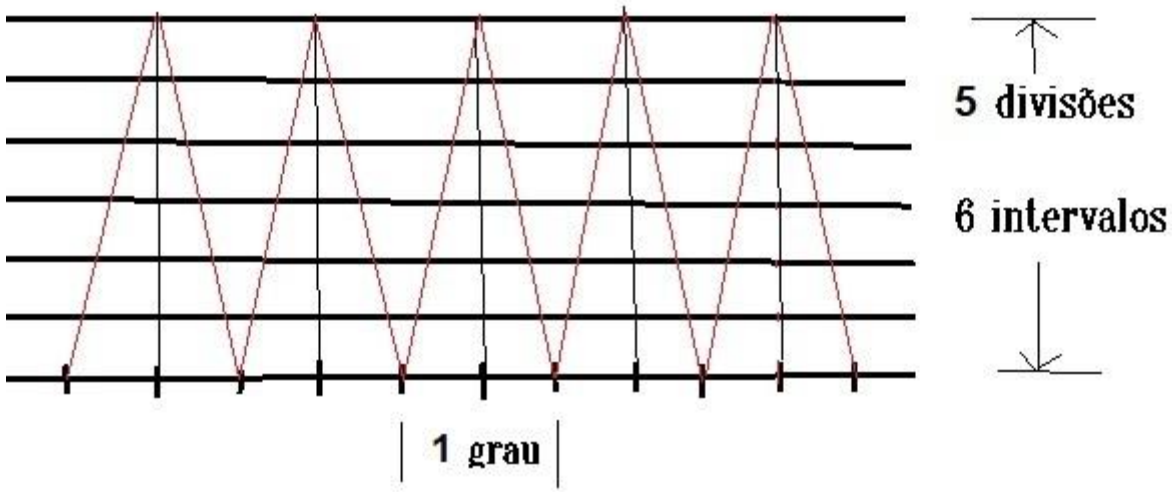
We also had a very large quadrant made, which is shown here [Fig. 5] denoted by BDEC. It is called Mural, or Tichonicus, after the wall on which it is fixed. It is cast from solid brass and very finely polished. It is five inches wide and two inches thick, and the circumference is so large that it corresponds to a radius of nearly five cubits [194 cm]. Its degrees are in consequence extremely large and every single minute can be divided again into six subdivisions; thus ten seconds of arc are plainly distinguishable and even half this, or five seconds of arc, can be read without difficulty. This is all done by means of transversal points drawn according to our usual method.

This quadrant is fastened to a wall MPO, the plane of which points exactly towards the south. The fastening is by strong screws, so that the quadrant cannot be forced out of its proper position, which has been determined beforehand so that it corresponds entirely to the quadrant of the celestial meridian from the horizon to the zenith, in such a way, however, that it is exactly opposite to the latter. On another wall LMNB, which is at right angles to the first, pointing exactly east and west, is a brass cylinder, placed above, over the centre of the quadrant. The brass cylinder is gilded in order not to be damaged by the effects of the air, or otherwise soiled. It is seen near the letter A in a square hole in the same wall, which can be opened or closed with the aid of a shutter fitting into it. Ill this way it is possible when the sky is clear, to sight along both sides of the cylinder mentioned, and for this the pinnules near D or E are used. In fact this quadrant has two pinnules, so that either of them may be used, as desired, according to which one is best suited for the particular altitude that is to be measured. Each of them has a square plane, one hand broad. This corresponds exactly to the diameter of the cylinder mentioned above, so that one can aim through the parallel slits, which are placed on the pinnules on all four sides, in case it is intended to determine at the same time both the altitude and the transit over the meridian. If, however, the altitude alone is required, the observer, who is shown near F, makes the observation through the upper and the lower slit, and the corresponding sides of the cylinder, and then dictates the measured altitude to a second collaborator, who is sitting at the table G with a light, in order that he may enter the result in the ledger of observations. In order that the time of observation, and the very moment of the transit over the meridian may also be noted, a third collaborator, denoted by H, watches the clocks I and K, when the observer at F gives a signal, and the time is also entered in the ledger by the person sitting at G. The clocks mentioned are constructed in such a way, that they give not only the single minutes, but also the seconds, with the greatest possible accuracy, and imitating the uniform rotation of the heavens. Although it is difficult to make the clocks do this, one can, by exercising great care, to a certain degree attain this end. Also, if an error has crept in, it can be noted and corrected. Therefore it is necessary to

sunrise and sunset as well as the transits over the meridian, to the [illegible]
mechanism, which I invented myself and had constructed at my own expense, I humbly presented in the year 1590 [should be 1592] to His Majesty Christian, at the time King Elect, my most gracious lord, when seven years ago, in his fourteenth year, he was good enough graciously to visit me at Uraniborg on the island of Hven, accompanied by three of the noblest Councillors of the Realm, who at the time were at the head of the government, as well as by the rest of the Royal Household. This globe is still in his possession. But His Majesty, the King Elect, graciously presented to me in return a golden Chain, a magnificent work of art, of the kind which he was at the time wont to wear, beautifully worked and adorned with his own portrait. Above this globe, which I have just described, part of my library is represented at the letter V. At the letters Y and Z two portraits are hanging solidly mounted within a round frame. One of them represents the mighty King of the Danes, His Majesty King Frederick II, of illustrious memory, the other Her Majesty Queen Sophie, his high consort, those who always with royal and gracious favour supported me and my work. The other paintings that can be seen in the inner space are, first, above at the figures 1, 2, 3, 4 some of my instruments which are represented there. Further, below this framework, is shown my study. Here some tables are standing near 5 and 8, at which my astronomical assistants are generally occupied with calculations or other tasks of this kind. In the actual study there were four such tables. I used to keep at least six or eight, sometimes ten or twelve such collaborators, who came to me from all directions, and in addition a few boys and youths of the same kind. Between these tables at 6 and 7 one sees, behind a pillar, in the middle of the round study, the very large brass globe of six feet diameter [the diameter was 149 cm] which I shall depict and explain later on in the right place. Finally, below all this, at 9, 10, and 11, is seen my chemical laboratory, which was all in an underground basement. Here I had had arranged 16 chemical furnaces of different kinds and forms. From my youth I have been interested in this study, no less than in Astronomy, and I have cultivated it with great diligence and no small expense. In the last space, at the number 12, one of my hounds is lying at my feet. This dog was exceptionally faithful and sagacious and is shown in shape and size much as he was in life, a symbol not only of his noble race but also of sagacity and fidelity. This gives you a summary representation of the whole picture, as far as it was possible to render it on so small a scale. Three different distinguished artists made these paintings for me. My portrait was painted by the artist from Augsburg mentioned, the buildings and that which is inside them was done by my architect Johannes Stenwinckel of Emden. The representation above of landscapes and mountains, however, in which a sunset is also seen, was added by the royal Kronborg-artist Johannes of Antwerp. Each of the three artists mentioned has distinguished himself beyond others in the particular field in which he is here exemplified. Finally there is above at RS an inscription over the portrait and the whole painting, as you can see. The use of the large quadrant is for determining the altitudes of the stars within one-sixth of a minute, by sighting through the upper and lower slits of one of the pinnules and along the two corresponding sides of the cylinder, and reading off the altitude on the outer rim of the quadrant in accordance with the position of this pinnule. It is also possible to find the moment of transit over the meridian by double sights with the pinnules and the cylinder, by using the accurate clocks that I have


EFFIGIES TYCHONIS BRAHE O.F.
ÆDIFICII ET INSTRUMENTORUM
ASTRONOMICORUM STRUCTORIS.
Aº. DOMINI 1587. ÆTATIS SUÆ 40.

O vernier do quadrante mural



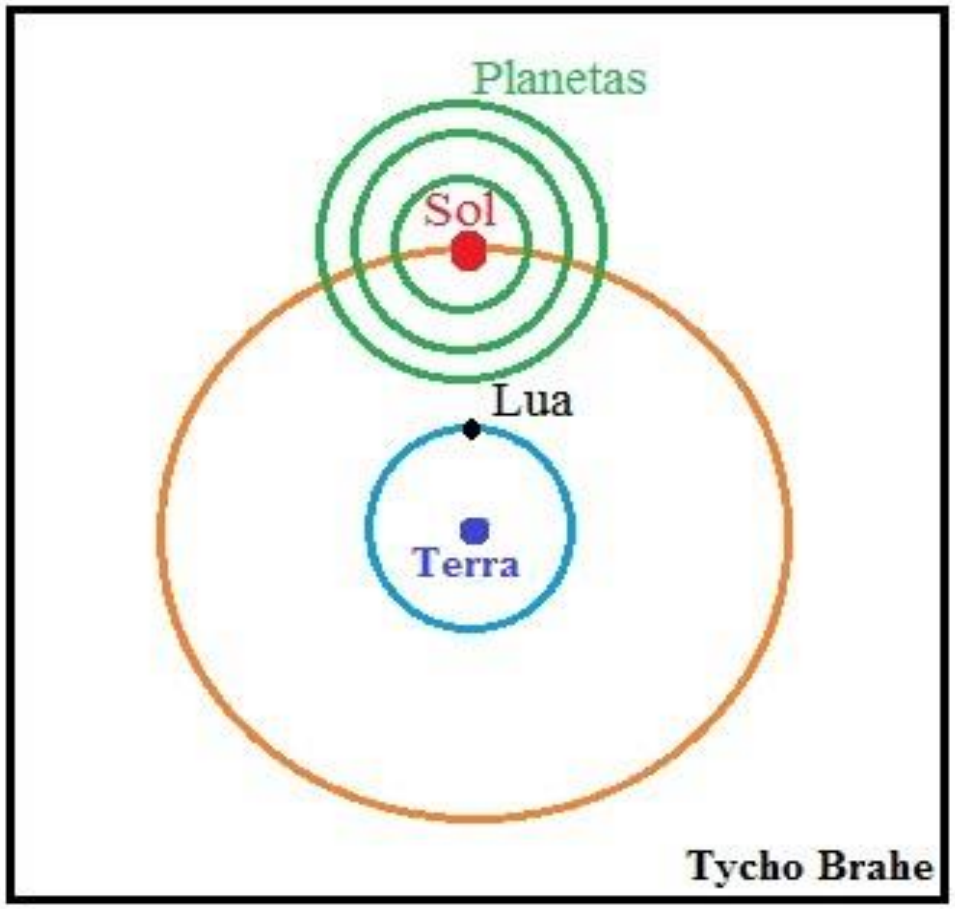
QUADRANTE MURAL:

18 x 5 graus = 90 graus
5 x 1 grau = 5 graus

Vernier permite a leitura de 1/12 de grau

Sistema do Mundo

modelo cosmológico de Tycho Brahe



Terra fixa: ausência de paralaxes estelares!

(PRECISÃO DE TYCHO BRAHE ERA AINDA INSUFICIENTE...)

PRIMEIRA PARALAXE ESTELAR: 1838

Estrela: 61 Cygni

→ Friedrich Wilhelm Bessel (1784-1846)

Paralaxe: 0,3” (~ 1/100 erro típico de Tycho Brahe,

≈ 30” = 0,5’)

→ d = 11,4 anos-luz

- 1599: Já em Praga, contrata JOHANNES KEPLER para ajustar as observações ao seu “SISTEMA DO MUNDO”.
- 1601: Morte de Tycho Brahe. Kepler assume seu posto.

A "REVOLUÇÃO" KEPLERIANA

* POR UM ERRO DE 8' NOS AJUSTES DAS OBSERVAÇÕES DE MARTE REALIZADAS POR TYCHO BRAHE, KEPLER ABANDONA AS ÓRBITAS CIRCULARES DE COPÉRNICO.

* KEPLER: CONFIANÇA TOTAL EM TYCHO BRAHE ATÉ 2'!

* ... ENCONTROU ENTÃO AS ÓRBITAS ELÍPTICAS!

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