

História e Métodos da Astronomia Clássica

R. Boczko
IAG-USP

15
02
03

Mundo na Antigüidade



Estrelas (6000)

Lua

Marte

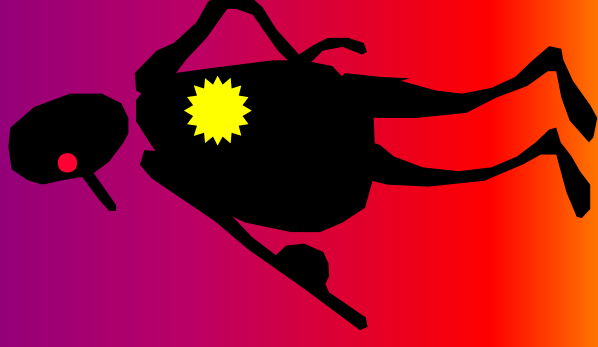
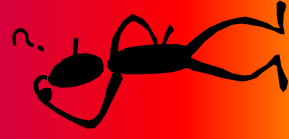
Mercúrio

Júpiter

Vênus

Saturno

Sol



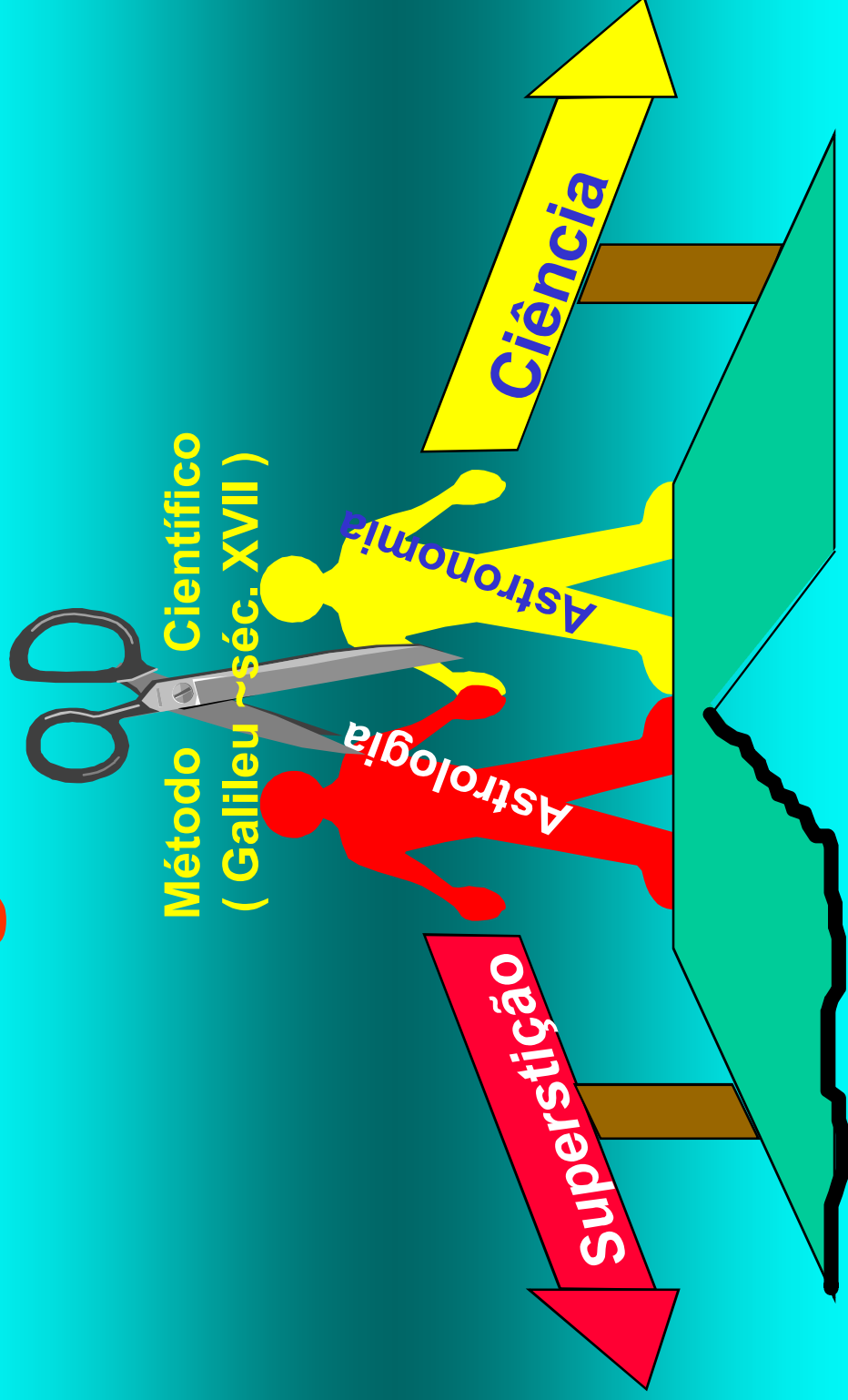
Astronomia x Astrologia

Astronomia é a Ciência que estuda os astros usando o método científico.

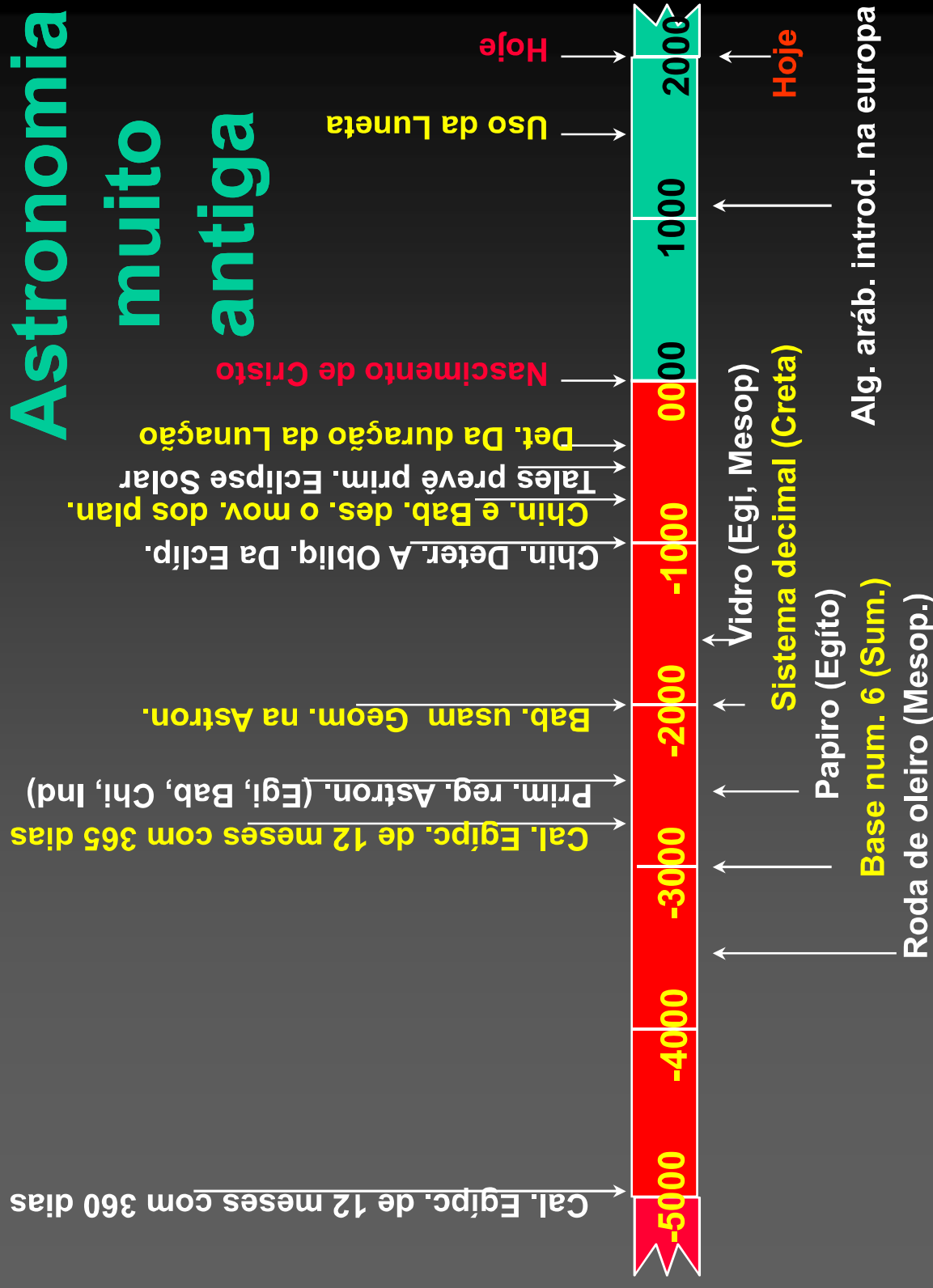


Astrologia é a **superstição** que **pretende** correlacionar as posições dos astros e suas influências sobre o homem.

Astrologia e Astronomia

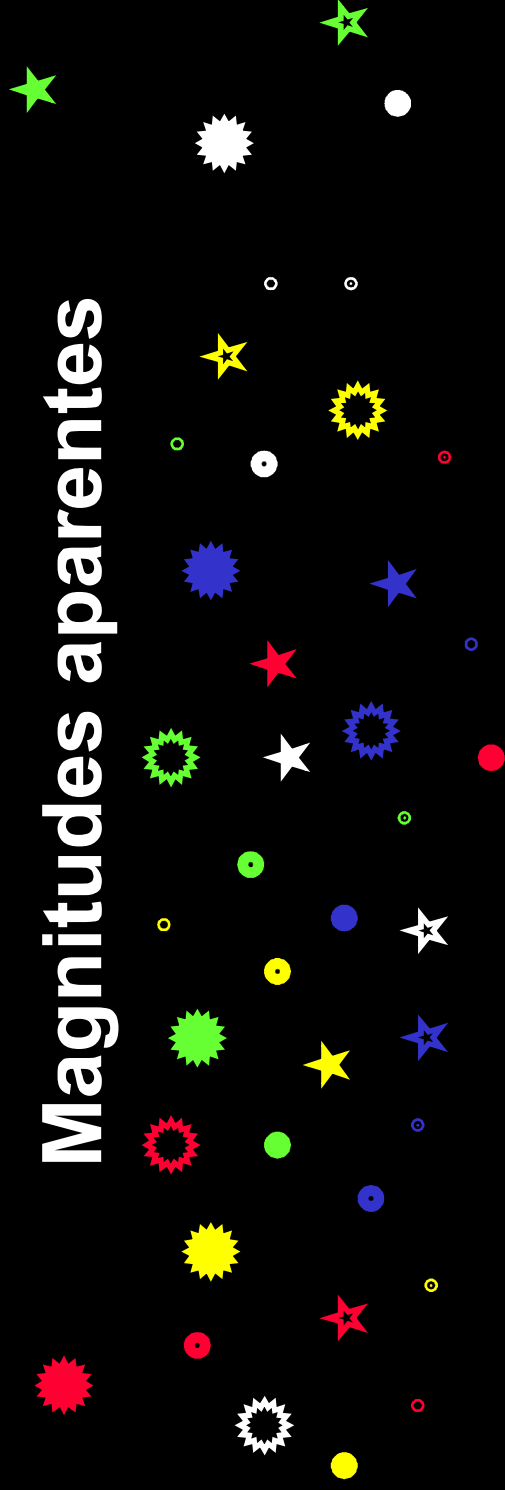


Astronomia muito antiga



Brilho aparente das estrelas

Magnitudes aparentes



**Classificação
das estrelas
segundo seus
brilhos aparentes
(Hiparcos, séc. II aC)**



Constelações

Constelação de Orion

Betelgeuse



α



γ Bellatrix

δ Mintaka
 ϵ Alnilan
 ζ Alnitaka



Mintaka



Alnilan

Alnitaka



κ

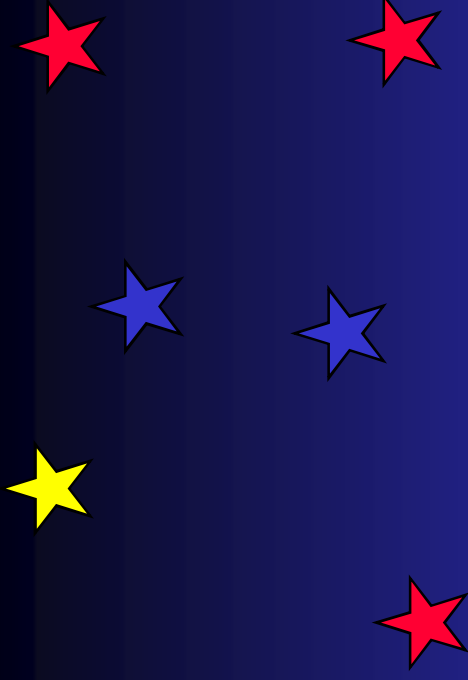
Saiph



β

Rigel

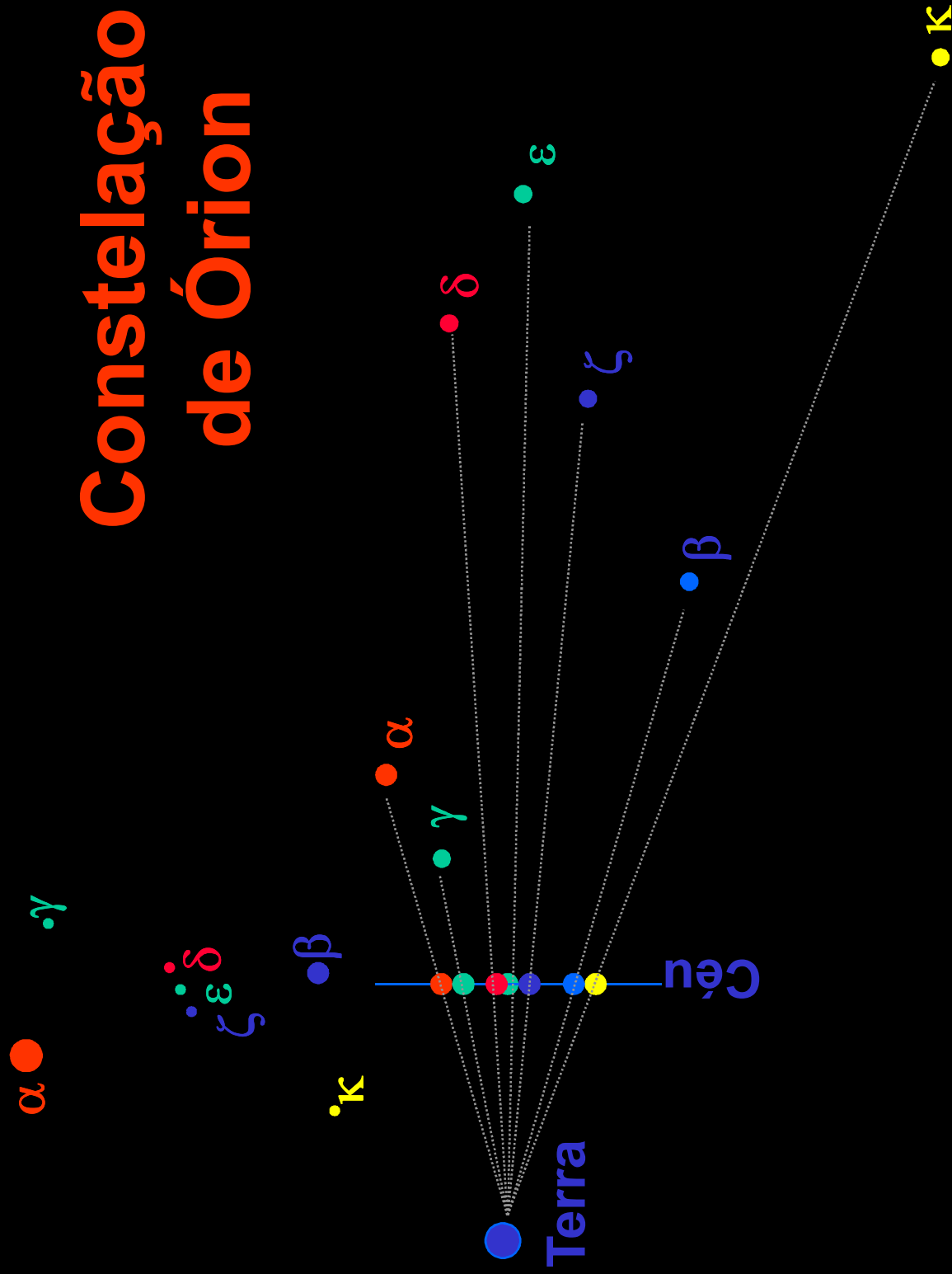
Constelação



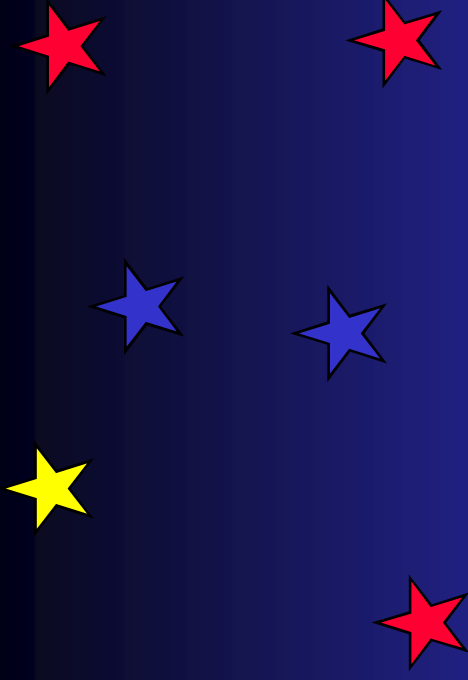
É um grupo de estrelas próximas
entre si.



Constelação de Órion



Constelação

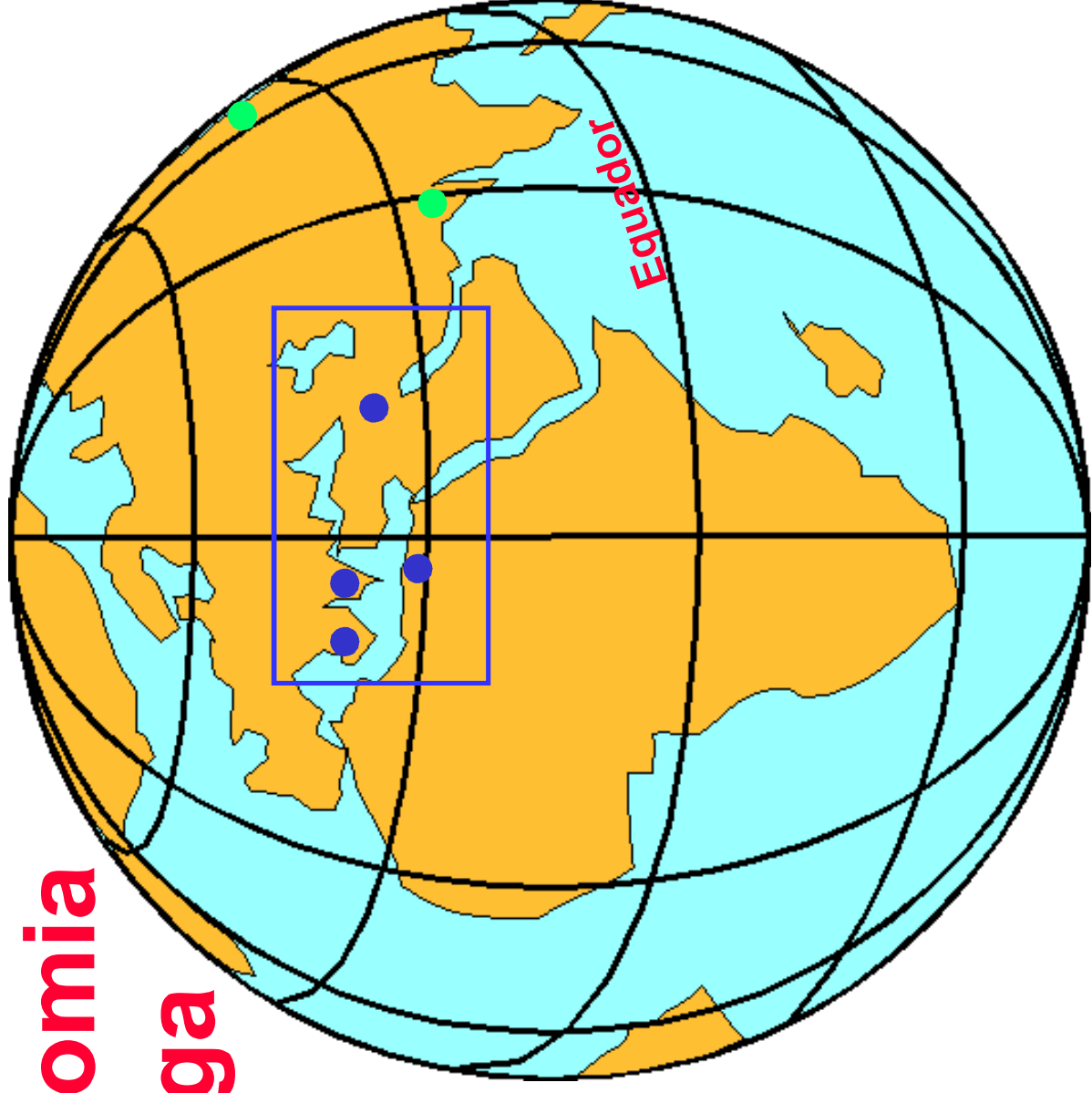


É um grupo **convencional** de estrelas.

Número de constelações = 88

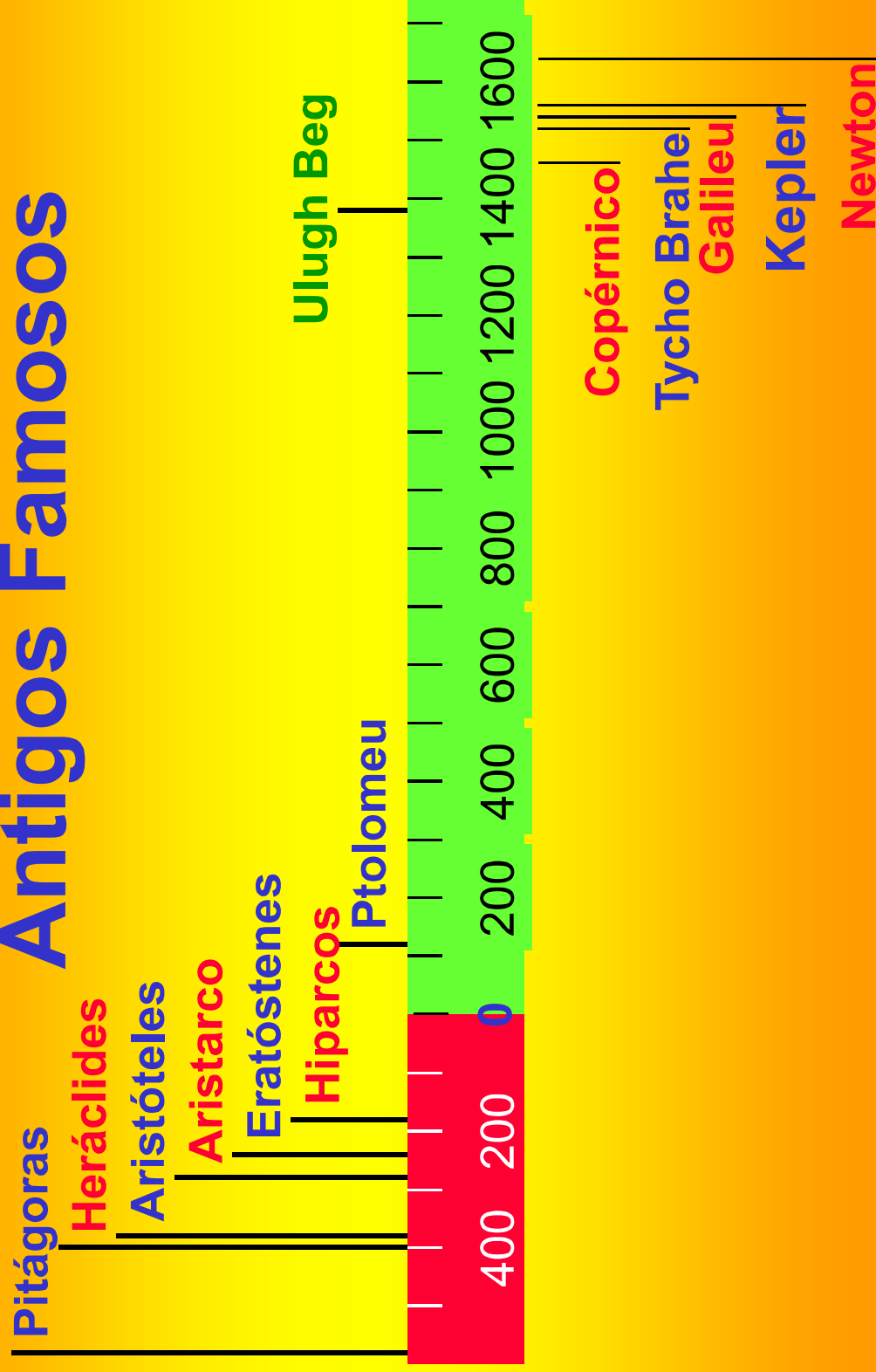
Quem, quando e onde?

Astronomia Antiga

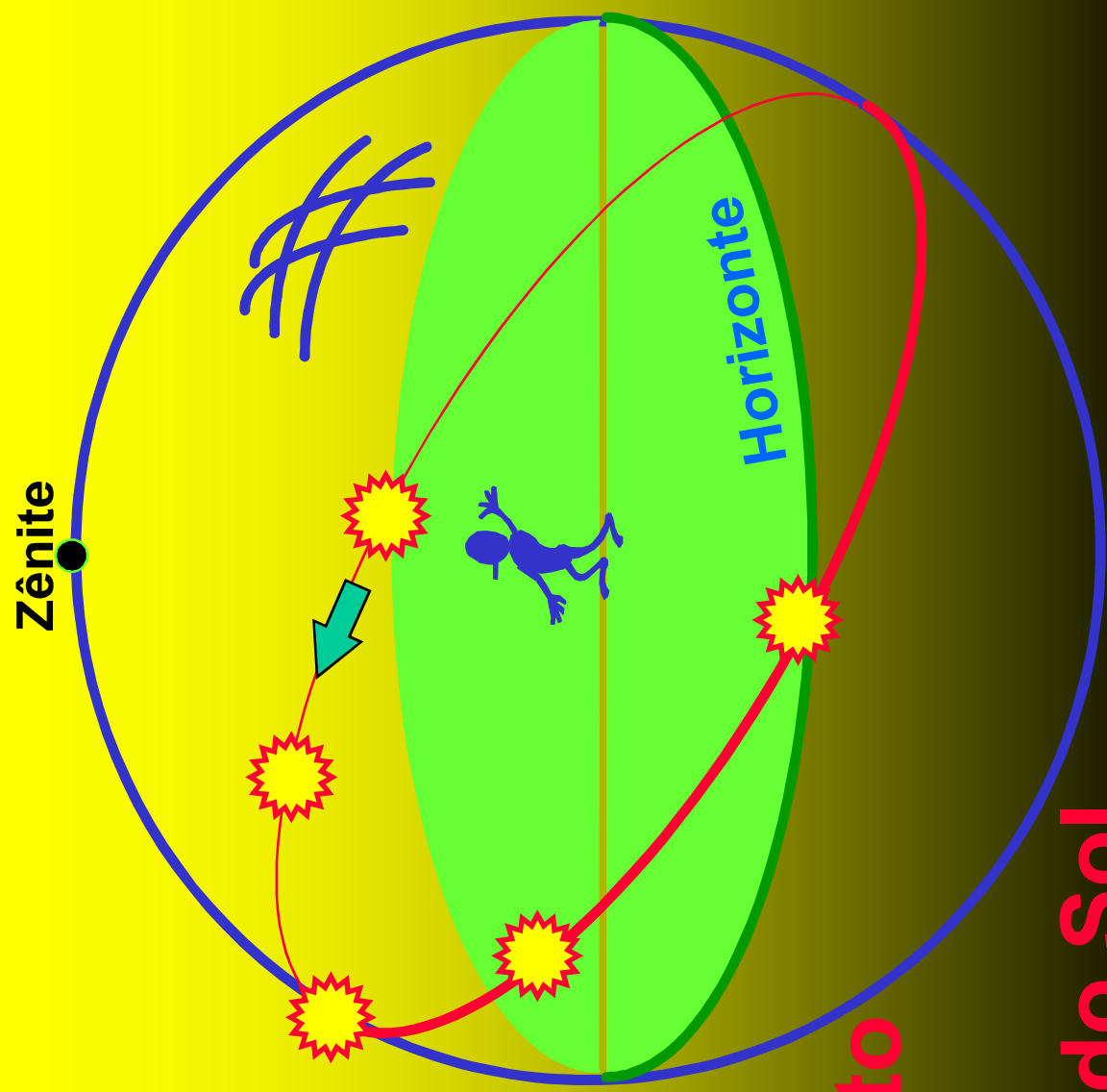


Filósofos e Astrônomos

Antigos Famosos

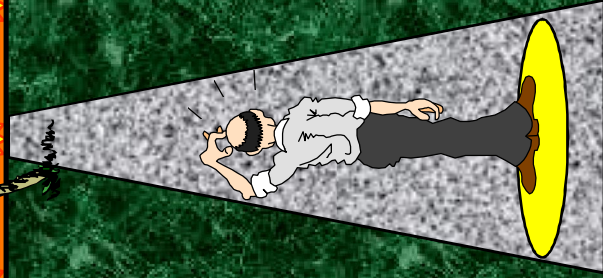


DIA



**Movimento
diurno
aparente do Sol**

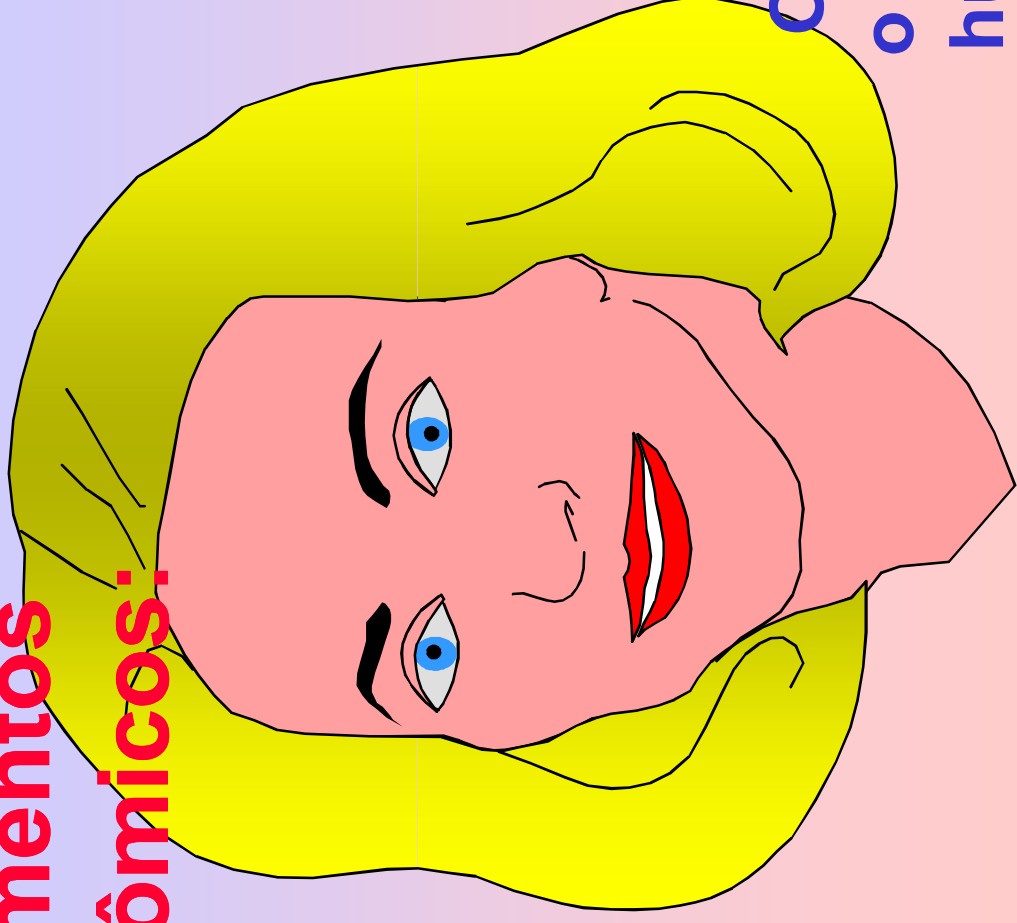
Nascer do Sol



Leste
é o ponto onde
o Sol nasce.
(?!)?

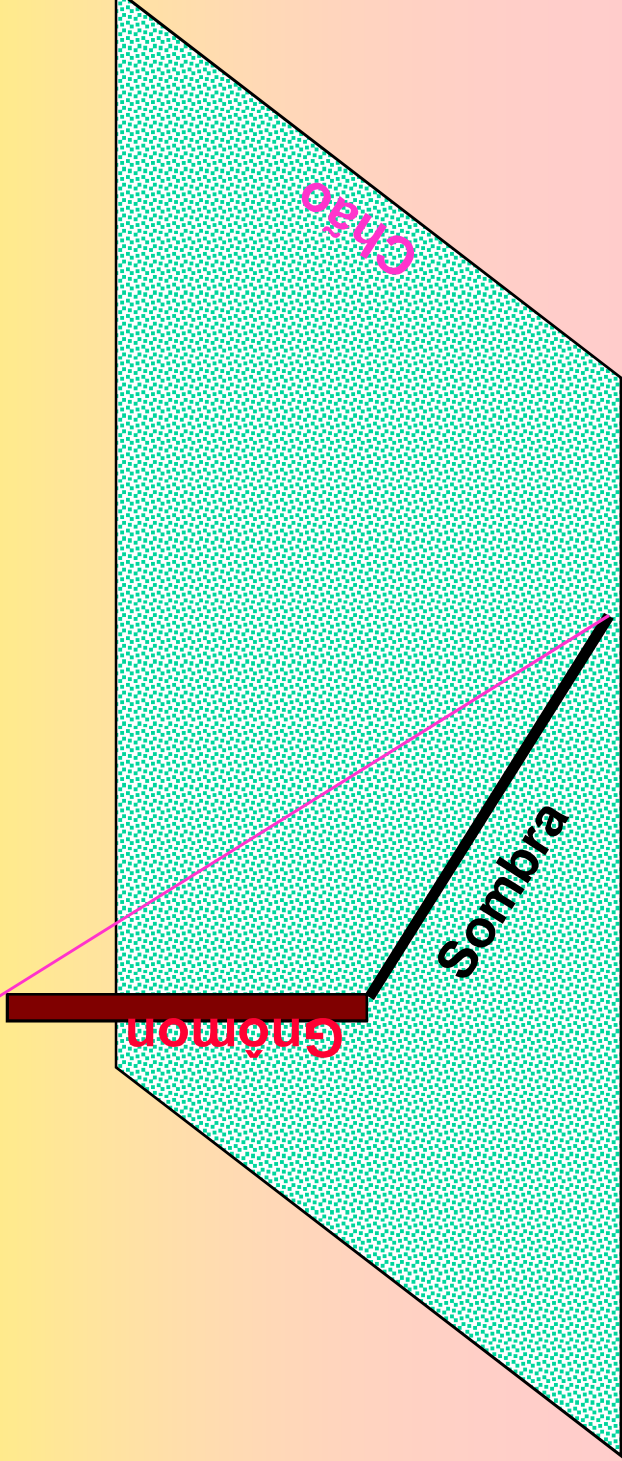
Instrumentos Astronômicos Antigos

**Primeiros
Instrumentos
Astronômicos:**

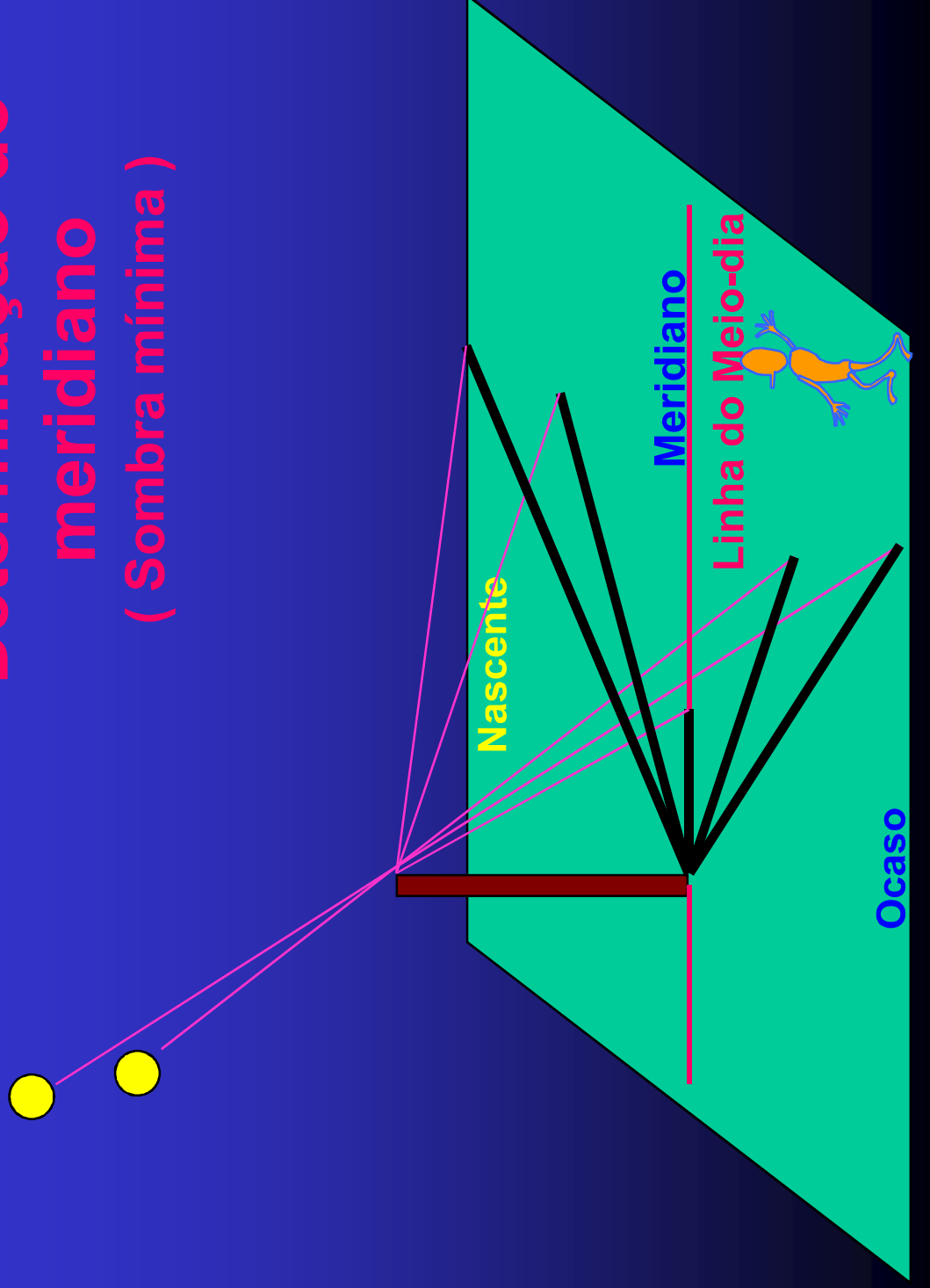


**O olho e
o cérebro
humanos**

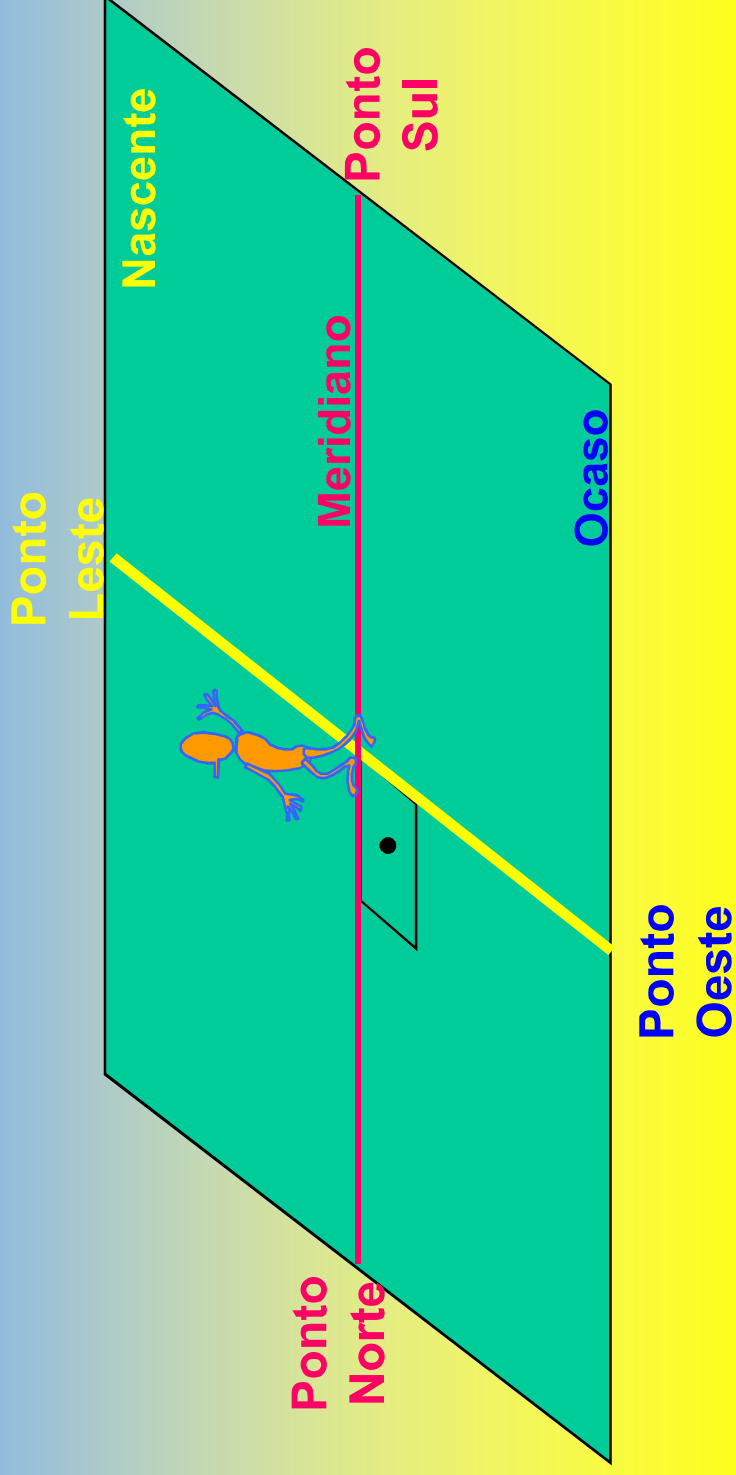
Gnômon (Relógio de Sol)



Determinação do meridiano (Sombra mínima)

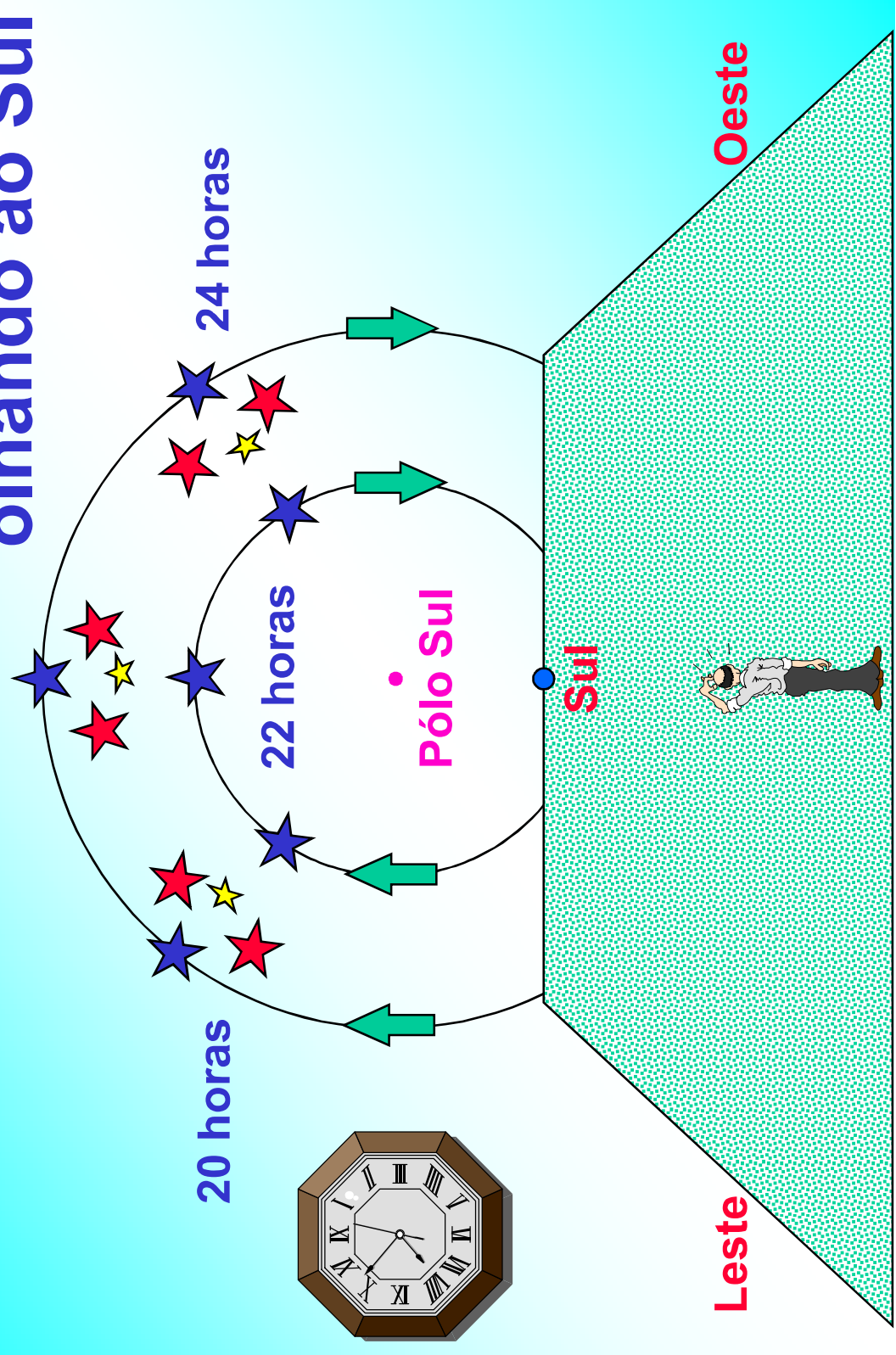


Pontos Cardeais

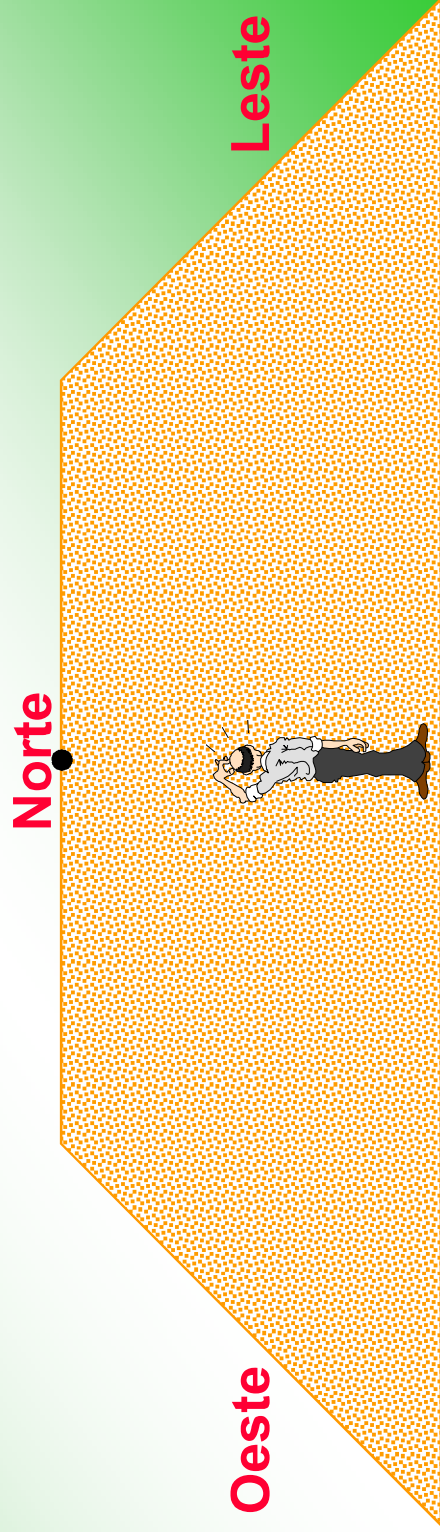
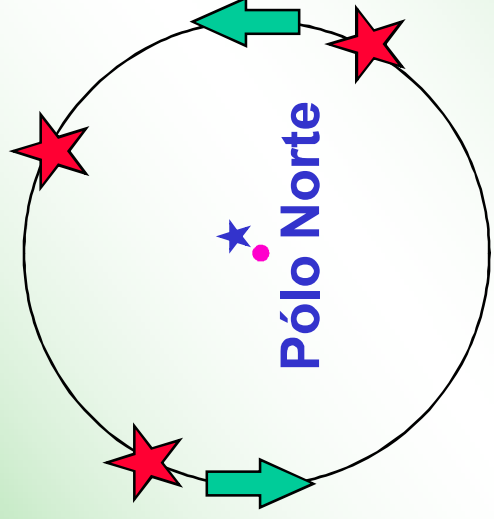


A Esfera Celeste

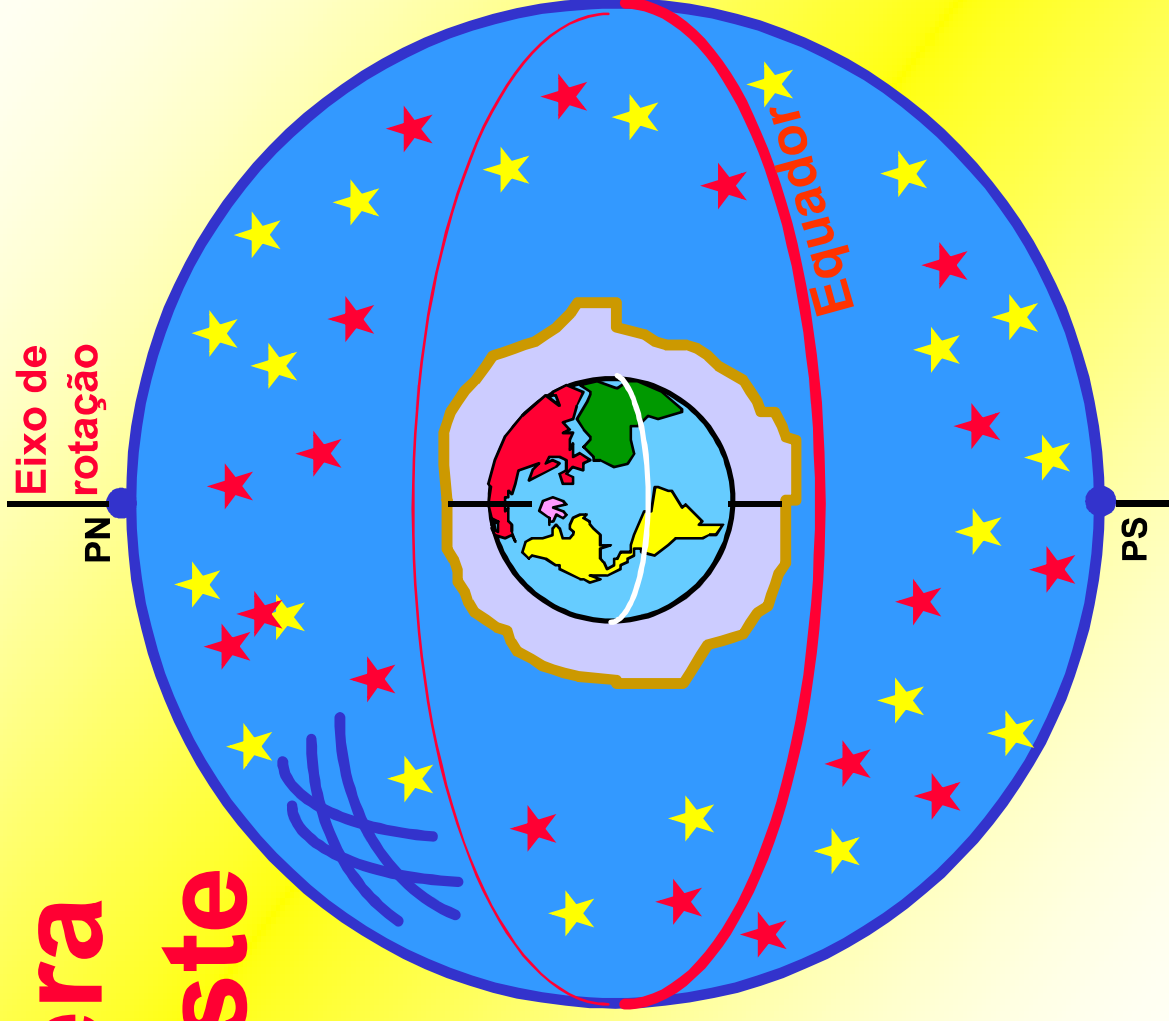
Movimento noturno aparente olhando ao Sul



Movimento noturno aparente de uma estrela circumpolar norte

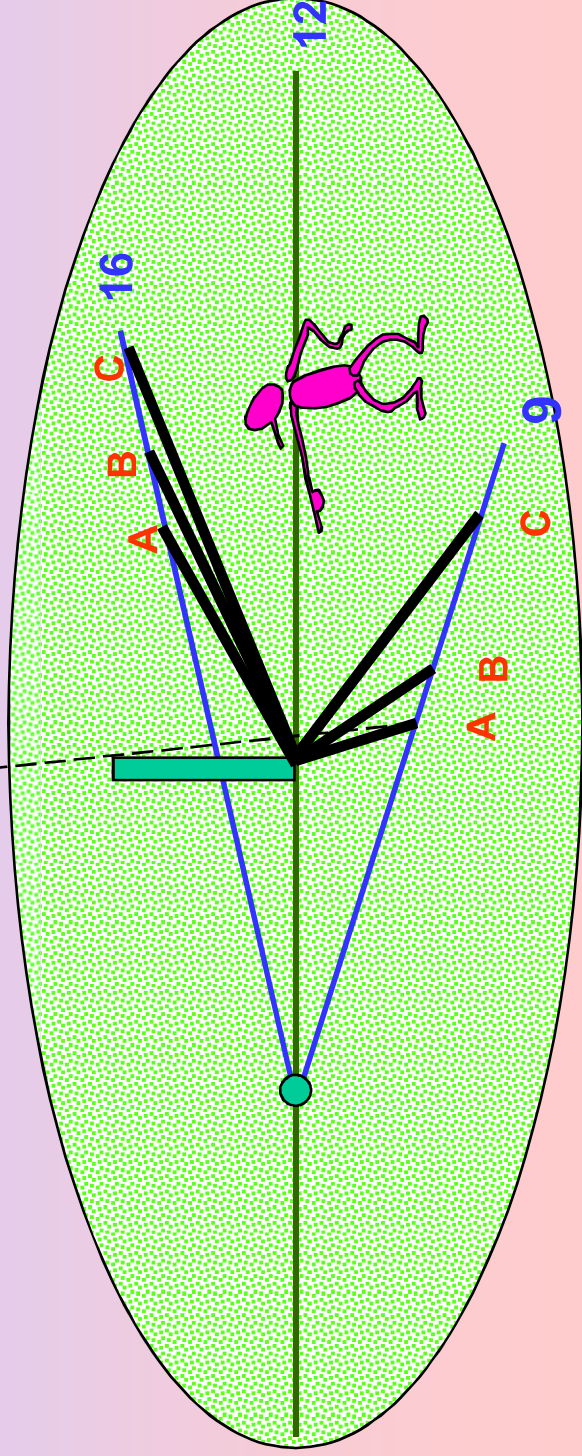


Esfera Celeste

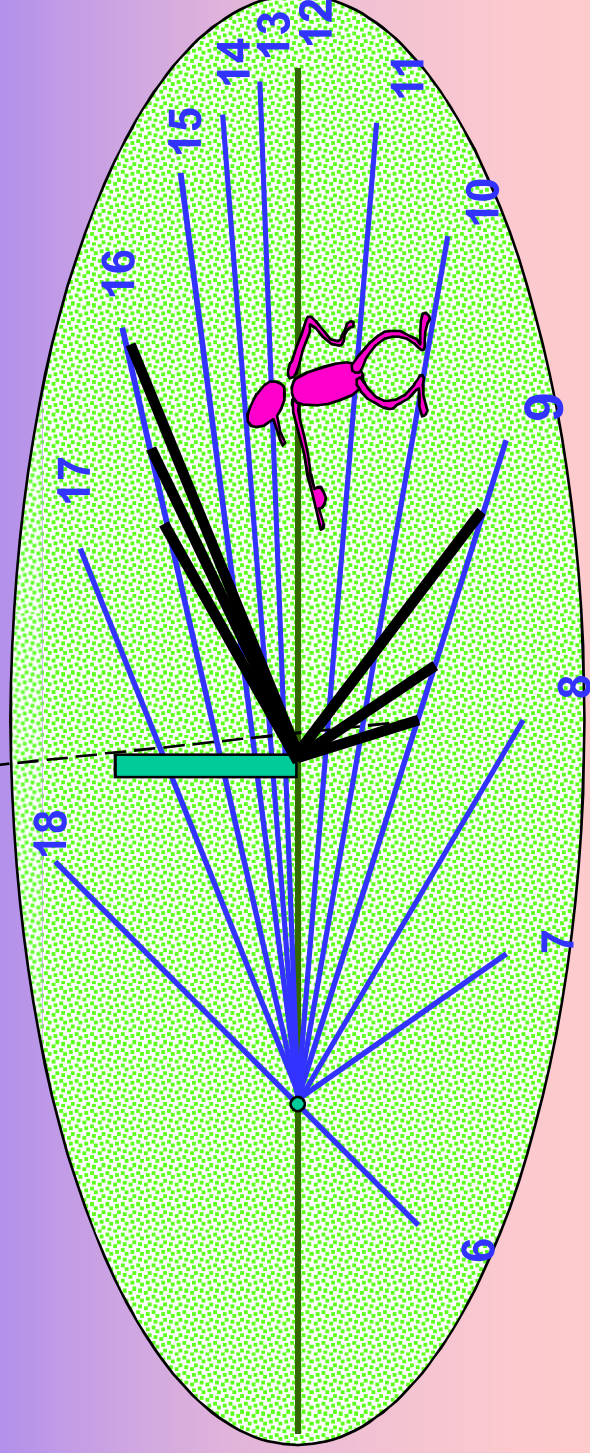


Relógios de Sol

Gnômon com mostrador horizontal



Gnômon com mostrador horizontal



Relógio de Vela

**Babilônicos
e Caldeus**

Sistema Sexagesimal

(60)

(12 = 60 / 5)

Dia = 12 + 12 horas

Romanos

Minuto (pequeno)

Segundo Minuto



12 h Meio dia

18 h Pôr do Sol

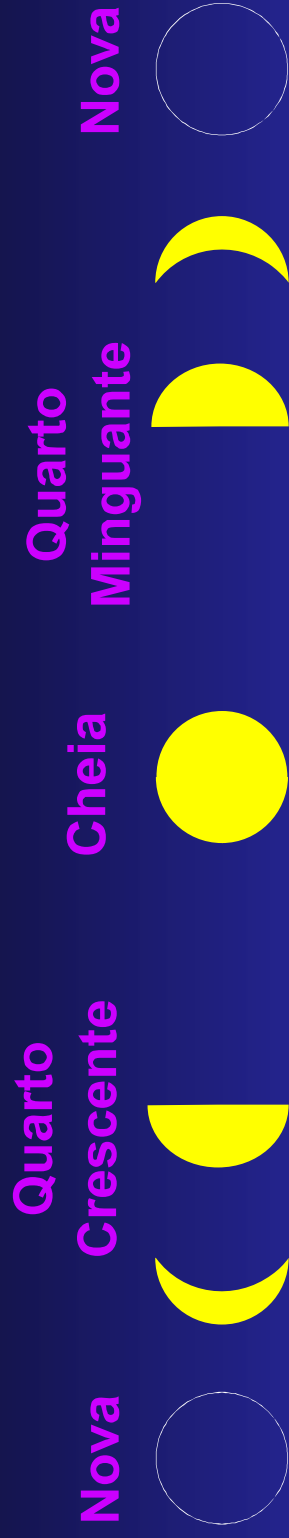
24 h Meia noite

06 h Nasc do Sol

12 h Meio dia

Fases da Lua

Fases da Lua



Nova

Crescente

Cheia

Minguante

Crescente

Minguante

Lunação

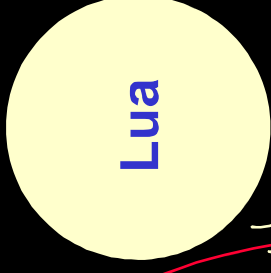
29,530589 dias ~ 29 d 12 h 44 m 03 s

Mês Lunar : 29 ou 30 dias

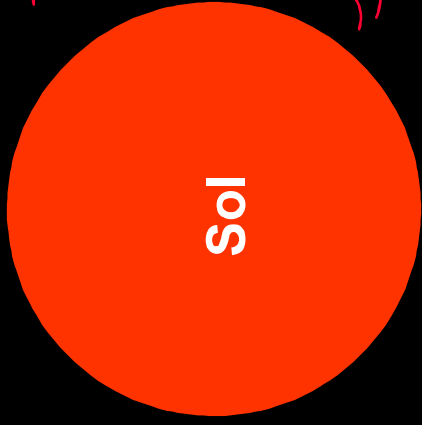
**Qual o motivo das
fases da Lua?**

Corpo Luminoso ou Iluminado

Iluminado



Lua



Sol

Luminoso

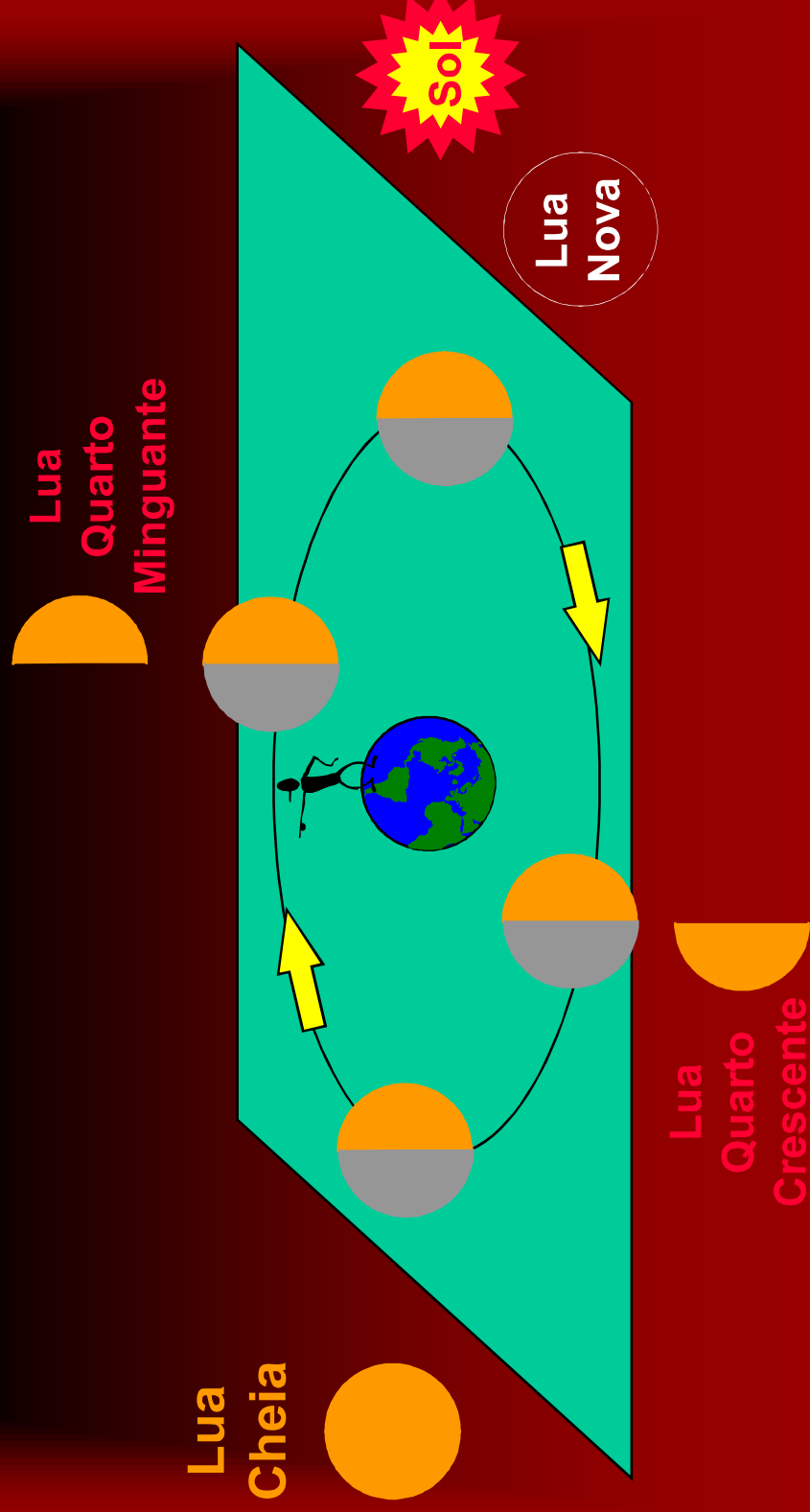


Terra

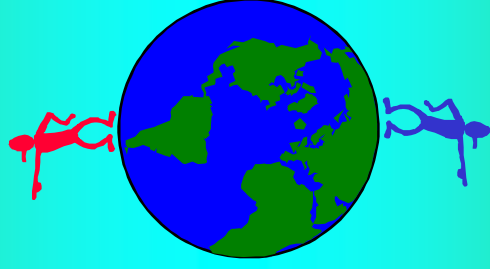
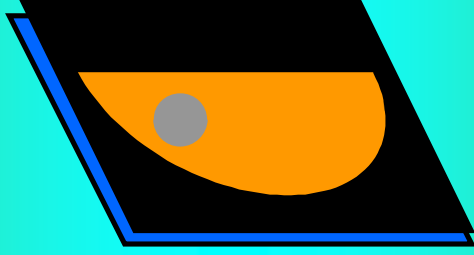


Motivos das fases da Lua

(Aristarco, séc. III a .C.)



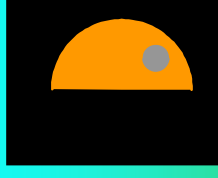
Visão da Lua



**Hemisfério
Sul**



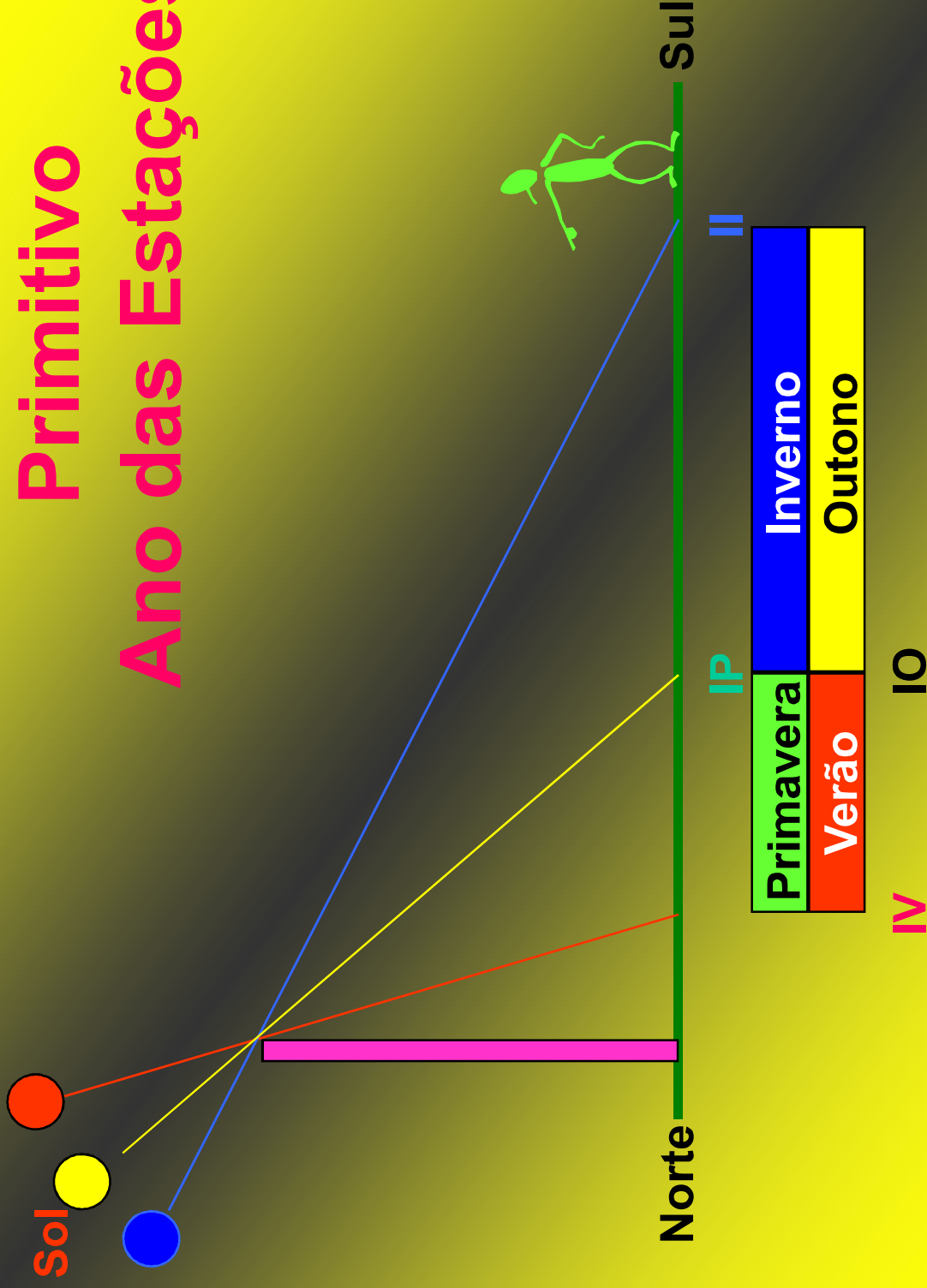
**Lua Quarto
Crescente**

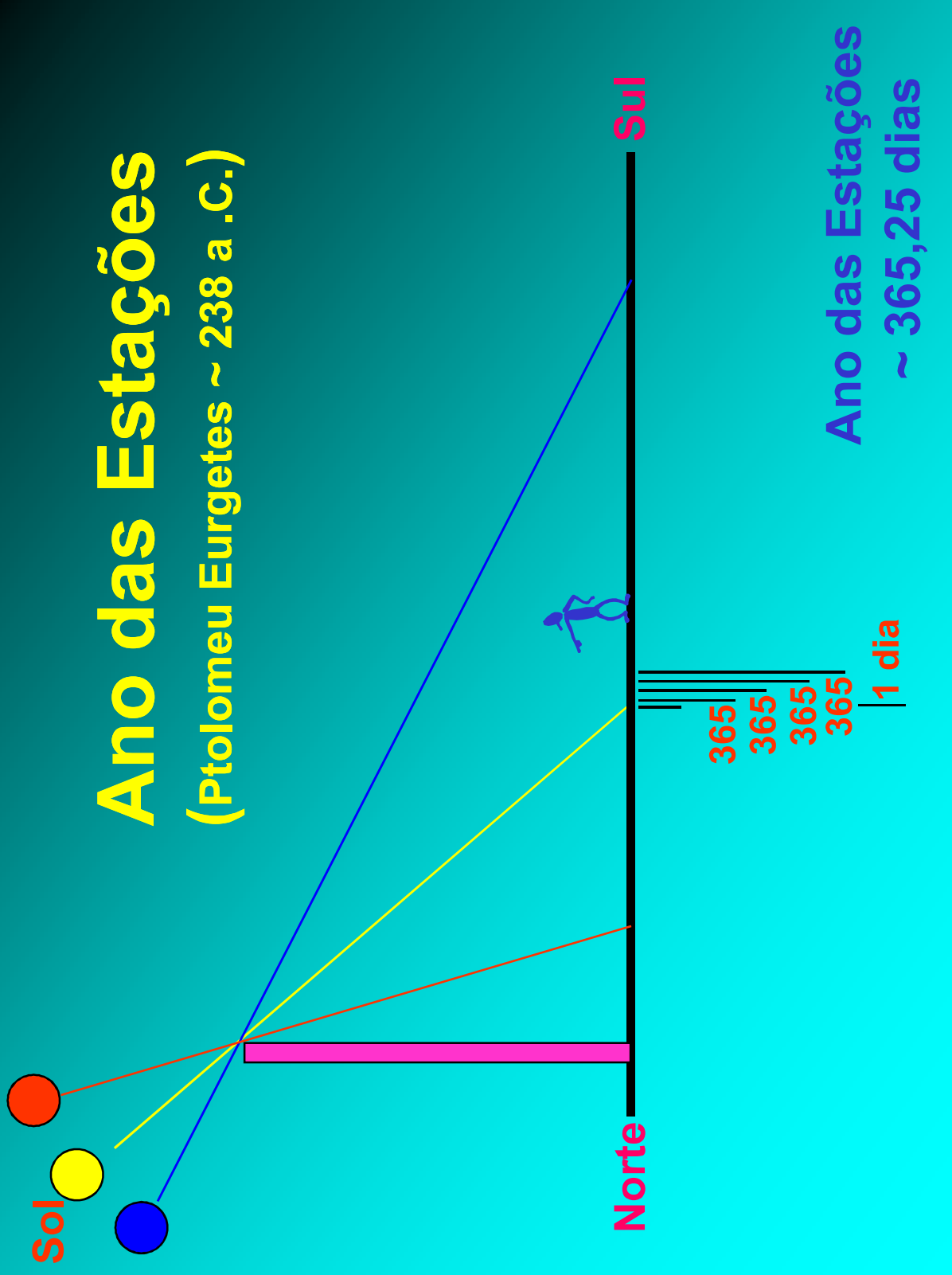


**Hemisfério
Norte**

ANO

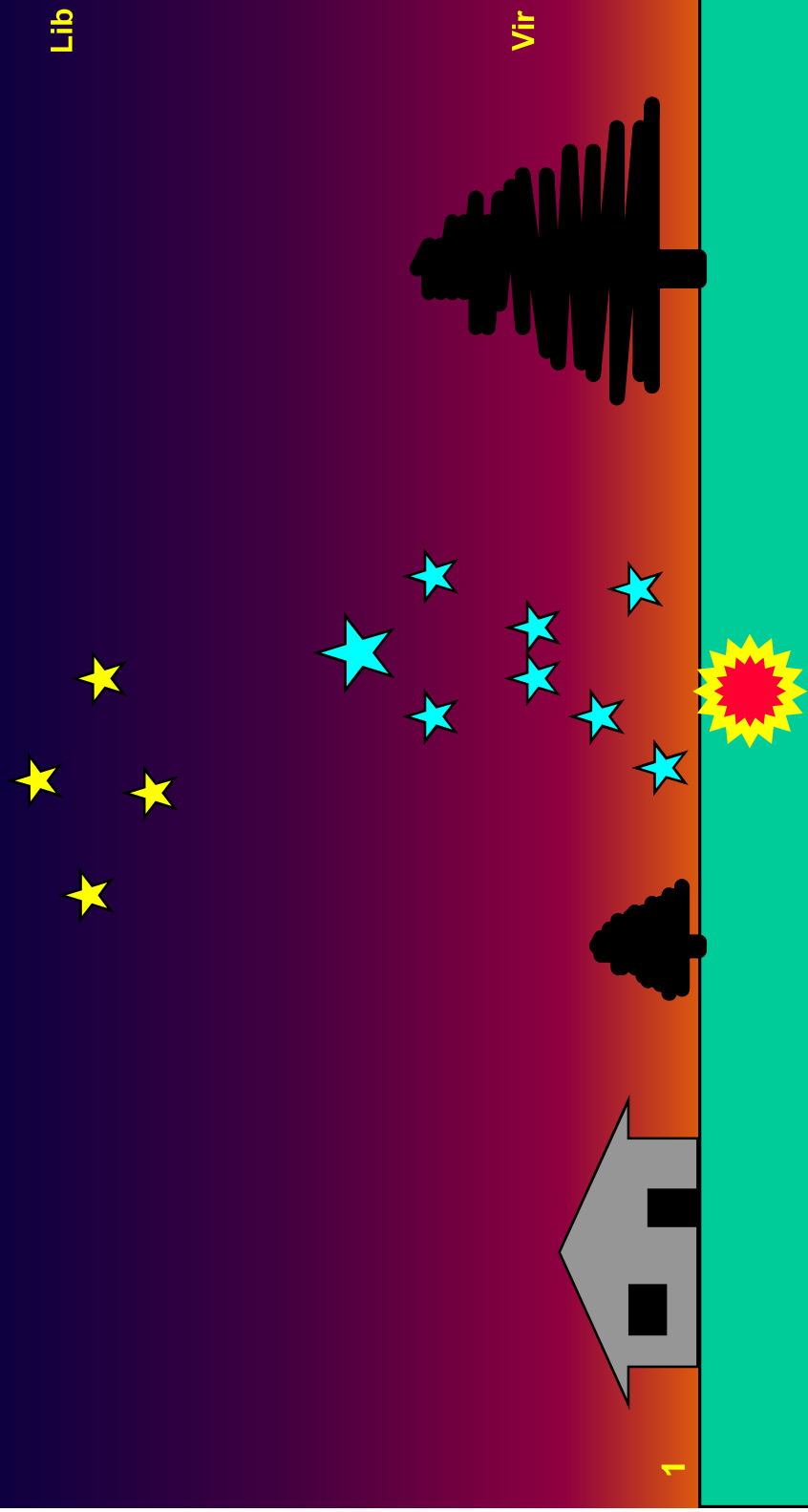
Primitivo Ano das Estações



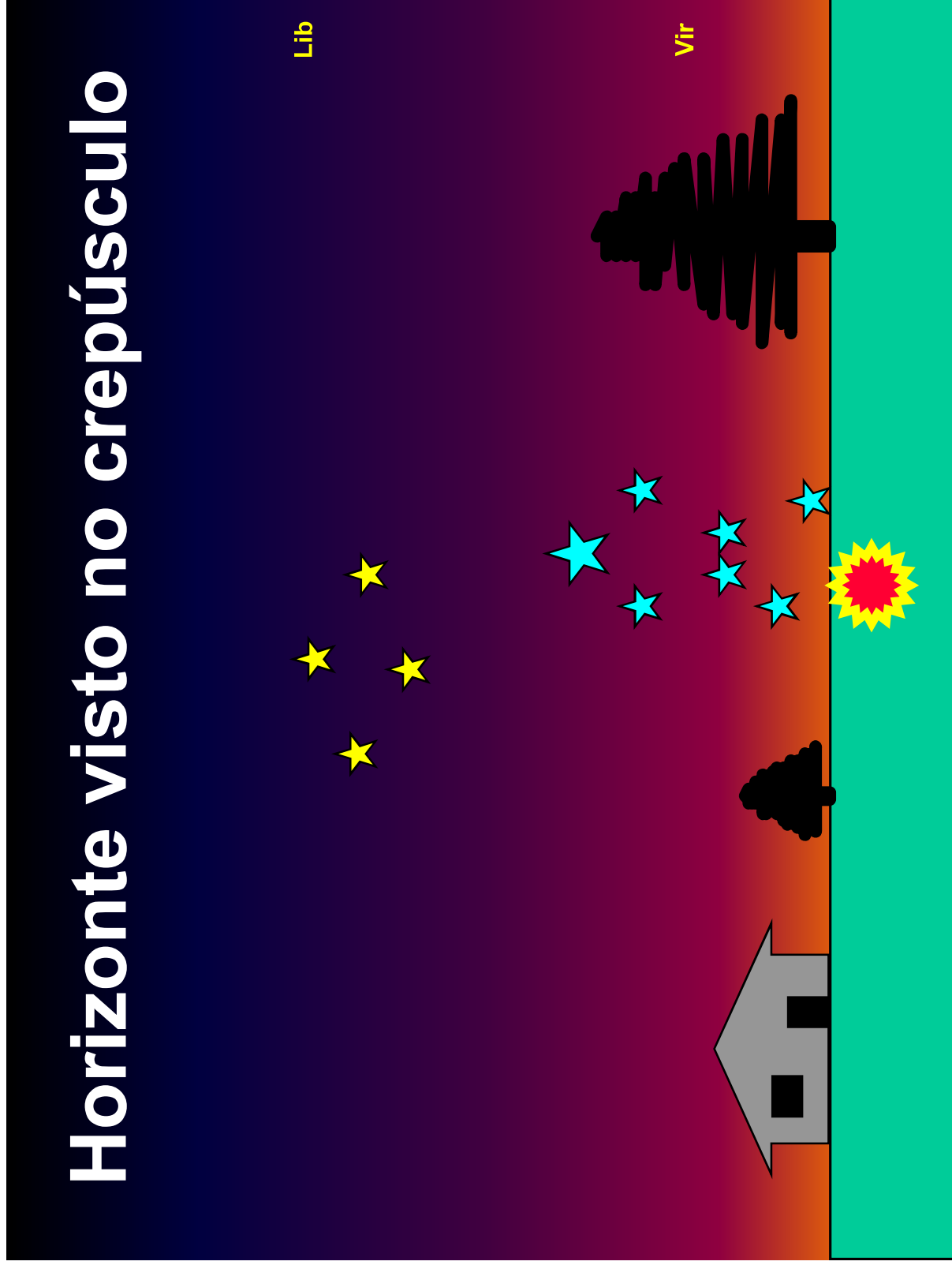


Movimento aparente do sol com relação às constelações

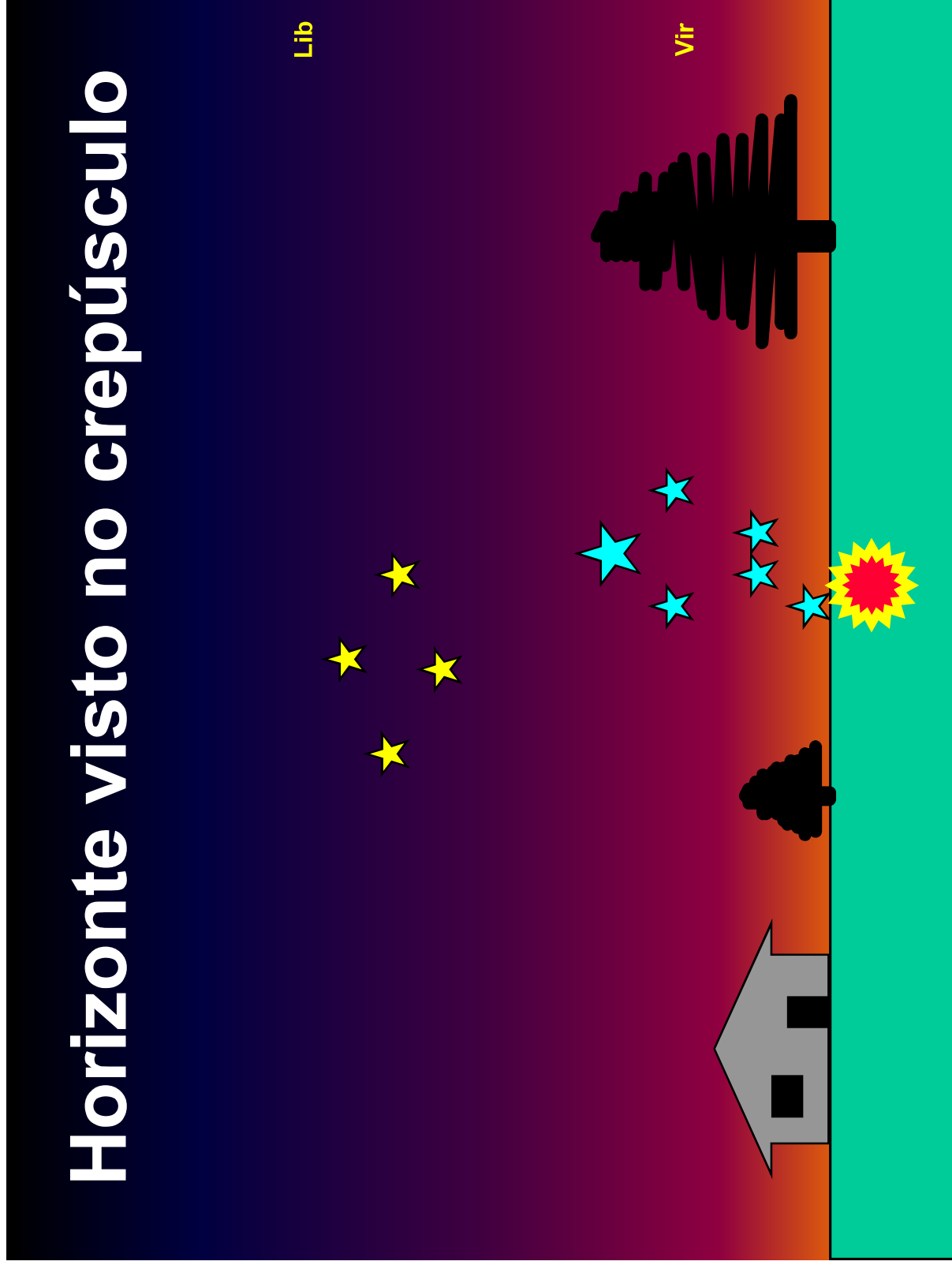
Horizonte visto no crepúsculo



Horizonte visto no crepúsculo



Horizonte visto no crepúsculo

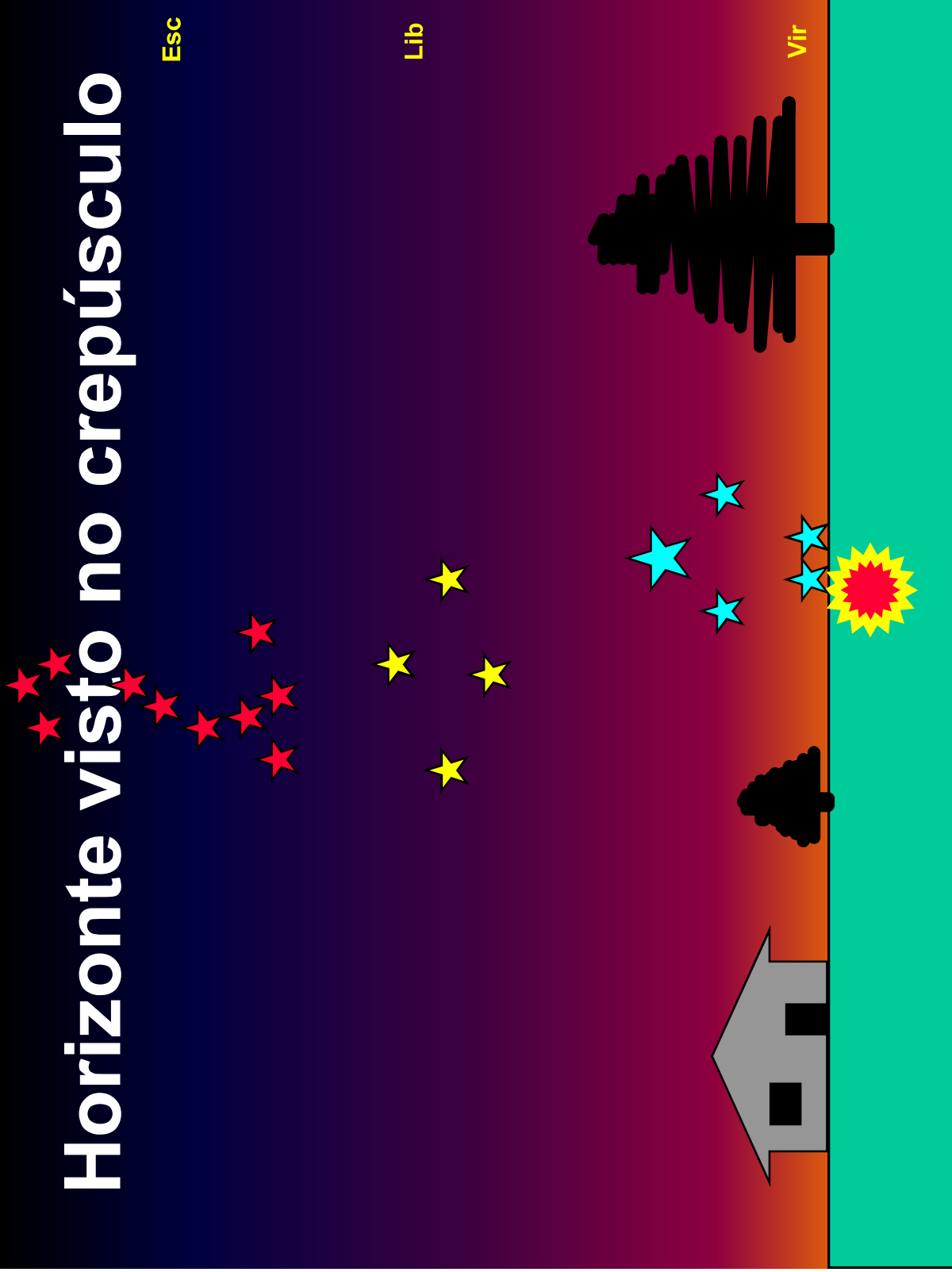


Horizonte visto no crepúsculo

Esc

Lib

Vir

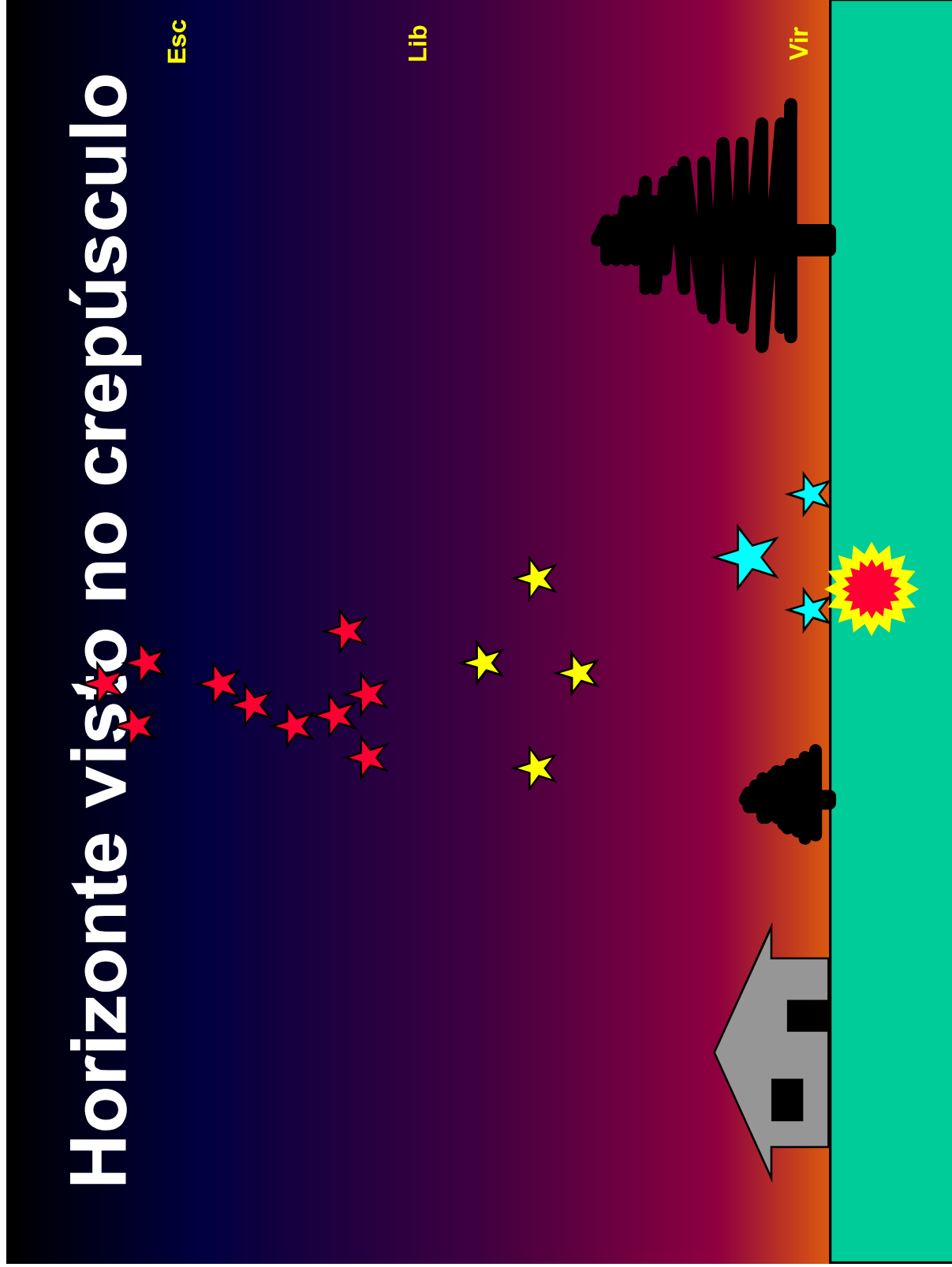


Horizonte visível no crepúsculo

Esc

Lib

Vir

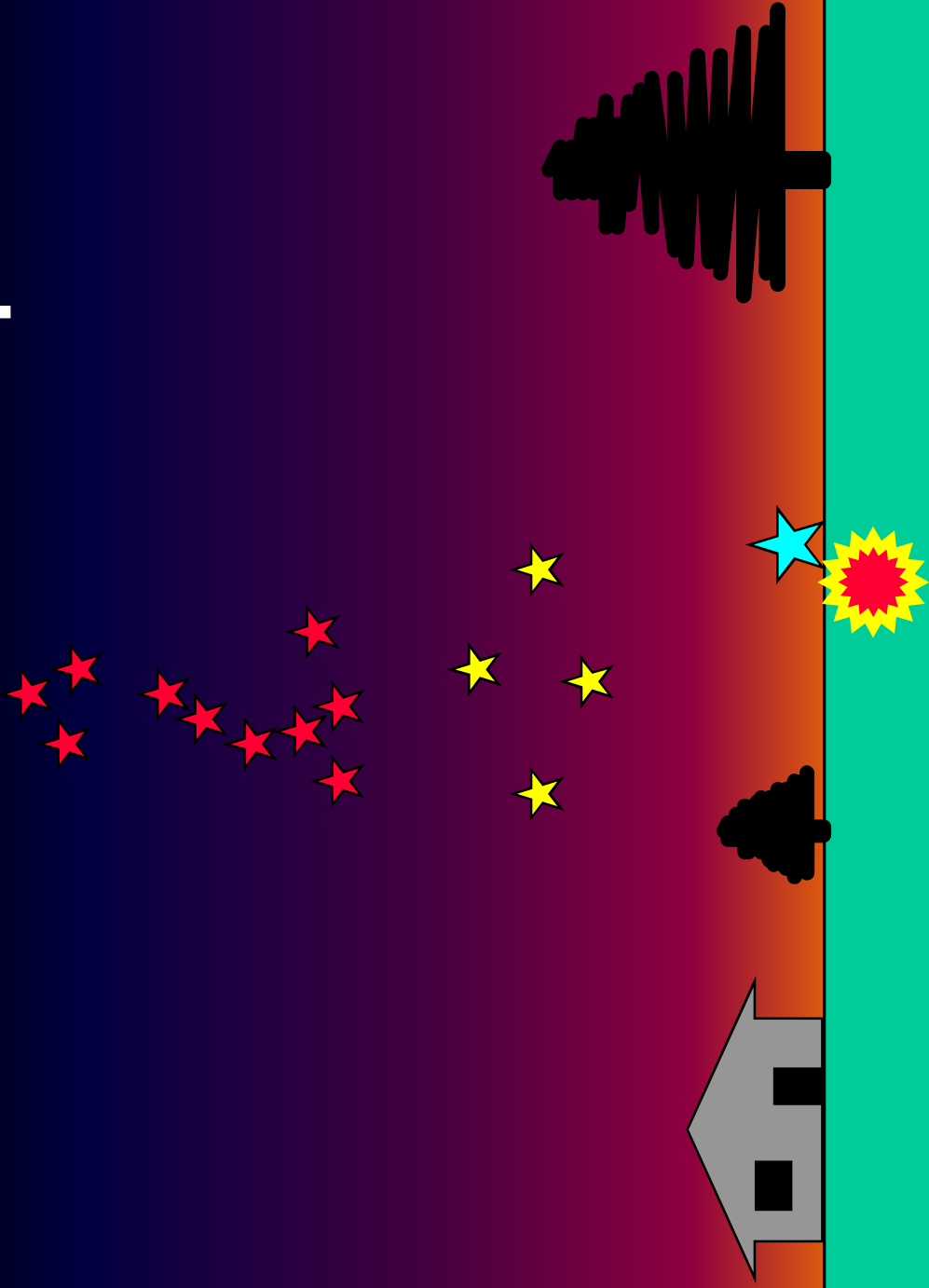


Horizonte visto no crepúsculo

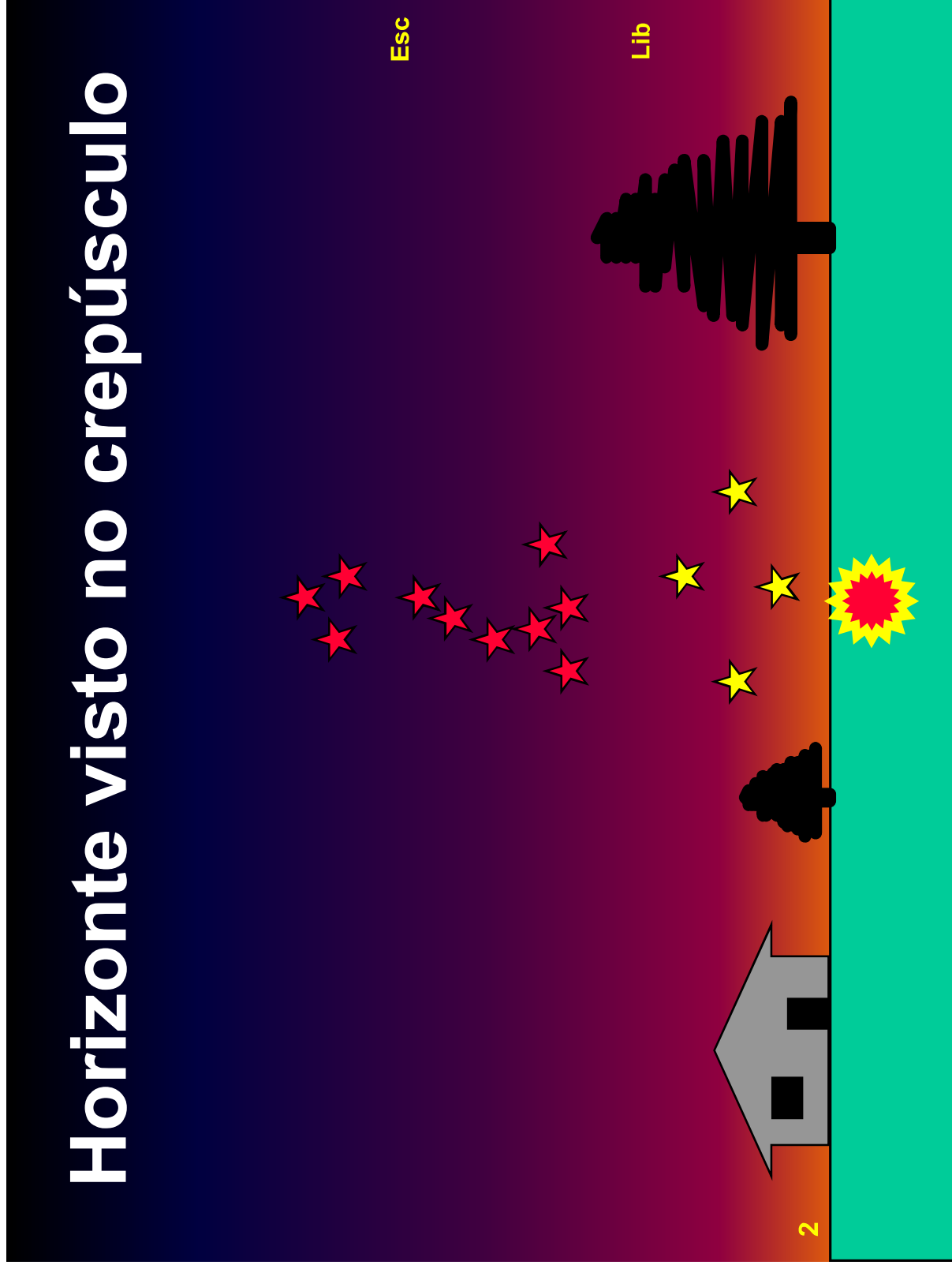
Esc

Lib

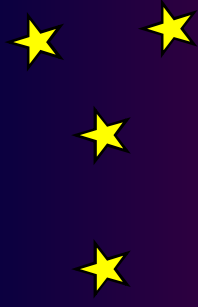
Vir



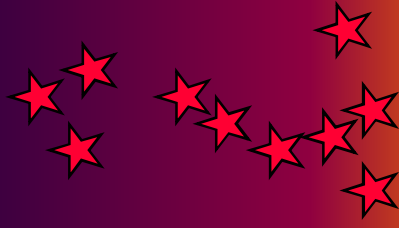
Horizonte visto no crepúsculo



Horizonte visto no crepúsculo



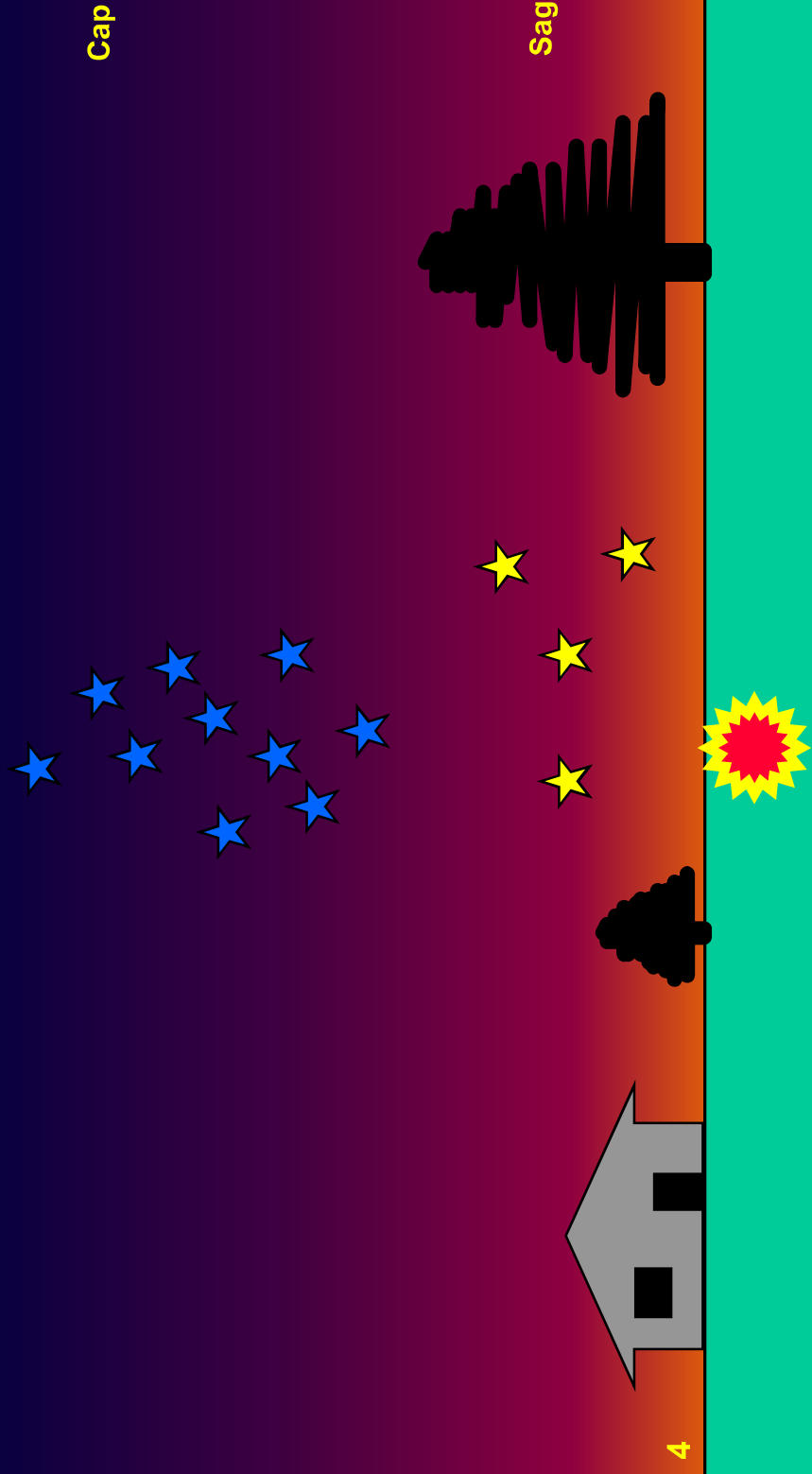
Sag



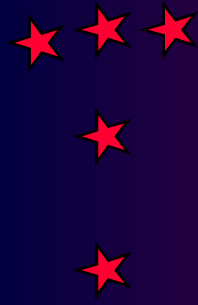
Esc



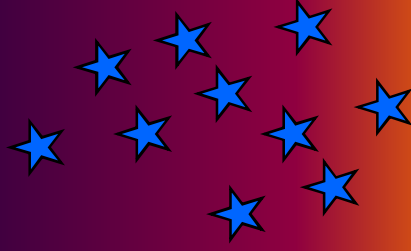
Horizonte visto no crepúsculo



Horizonte visto no crepúsculo



Aqu



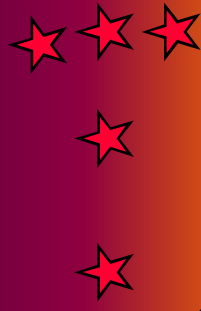
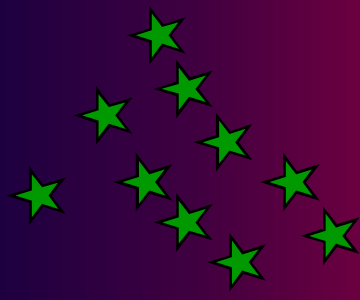
Cap



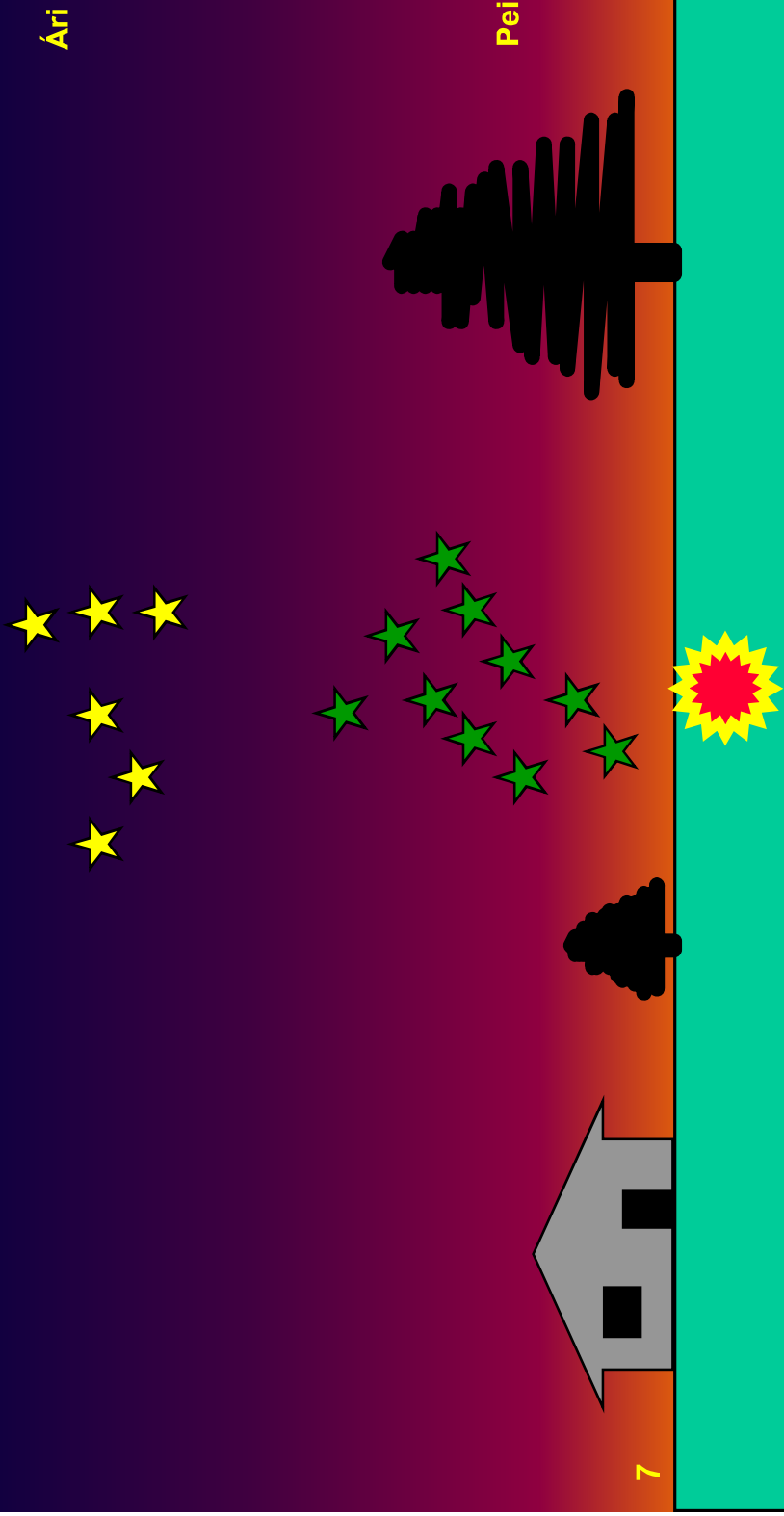
Horizonte visto no crepúsculo

Pei

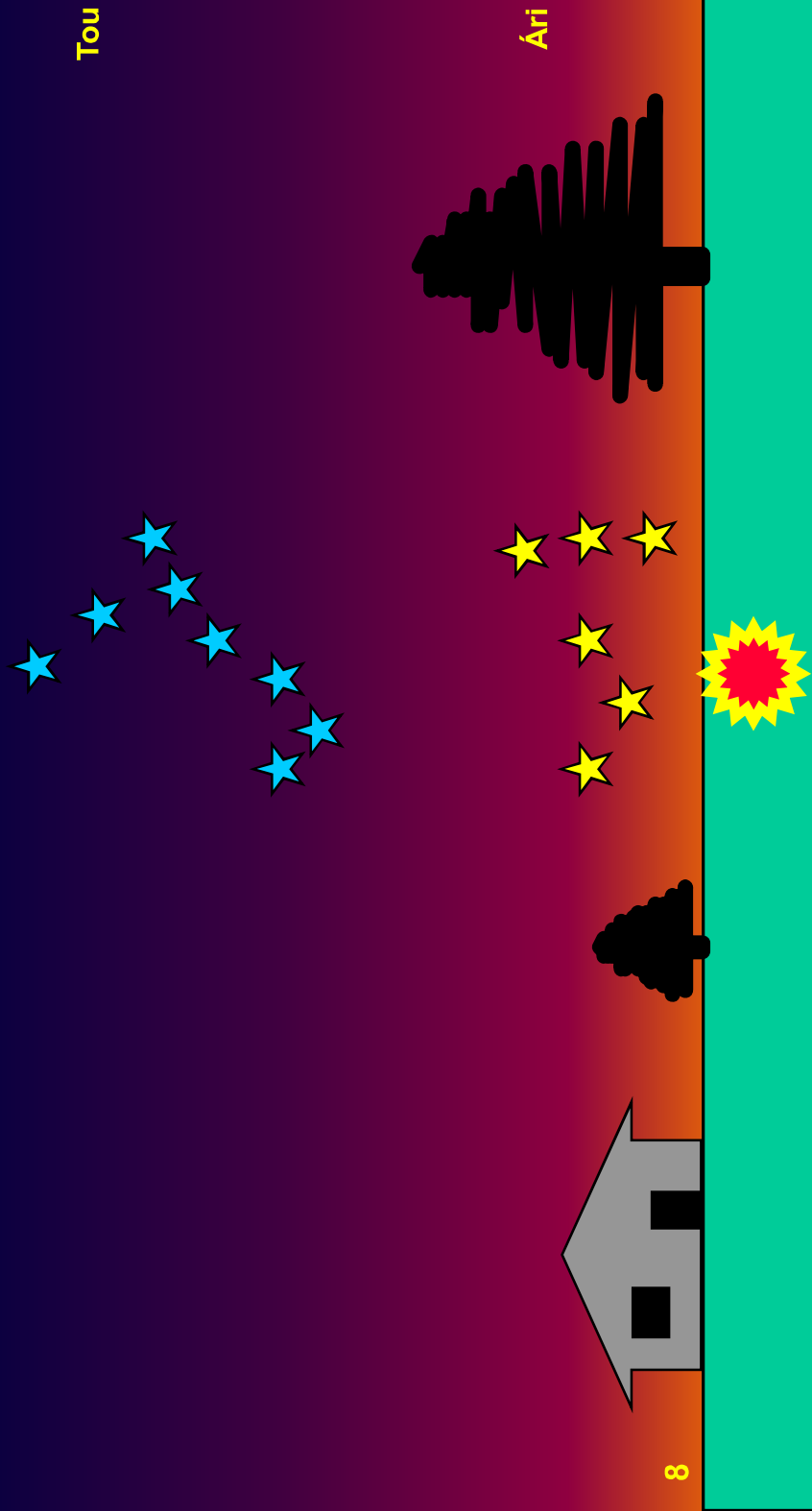
Aqu



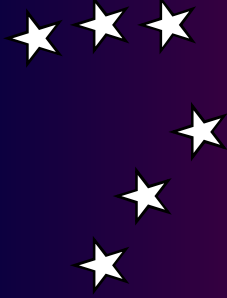
Horizonte visto no crepúsculo



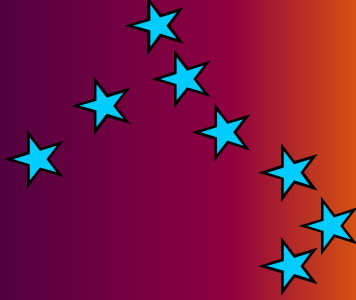
Horizonte visto no crepúsculo



Horizonte visto no crepúsculo



Gêm



Tou

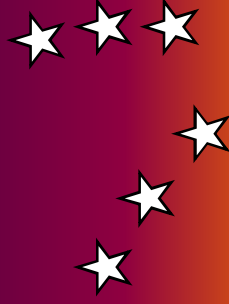


Horizonte visto no crepúsculo

Cân

Gêm

10

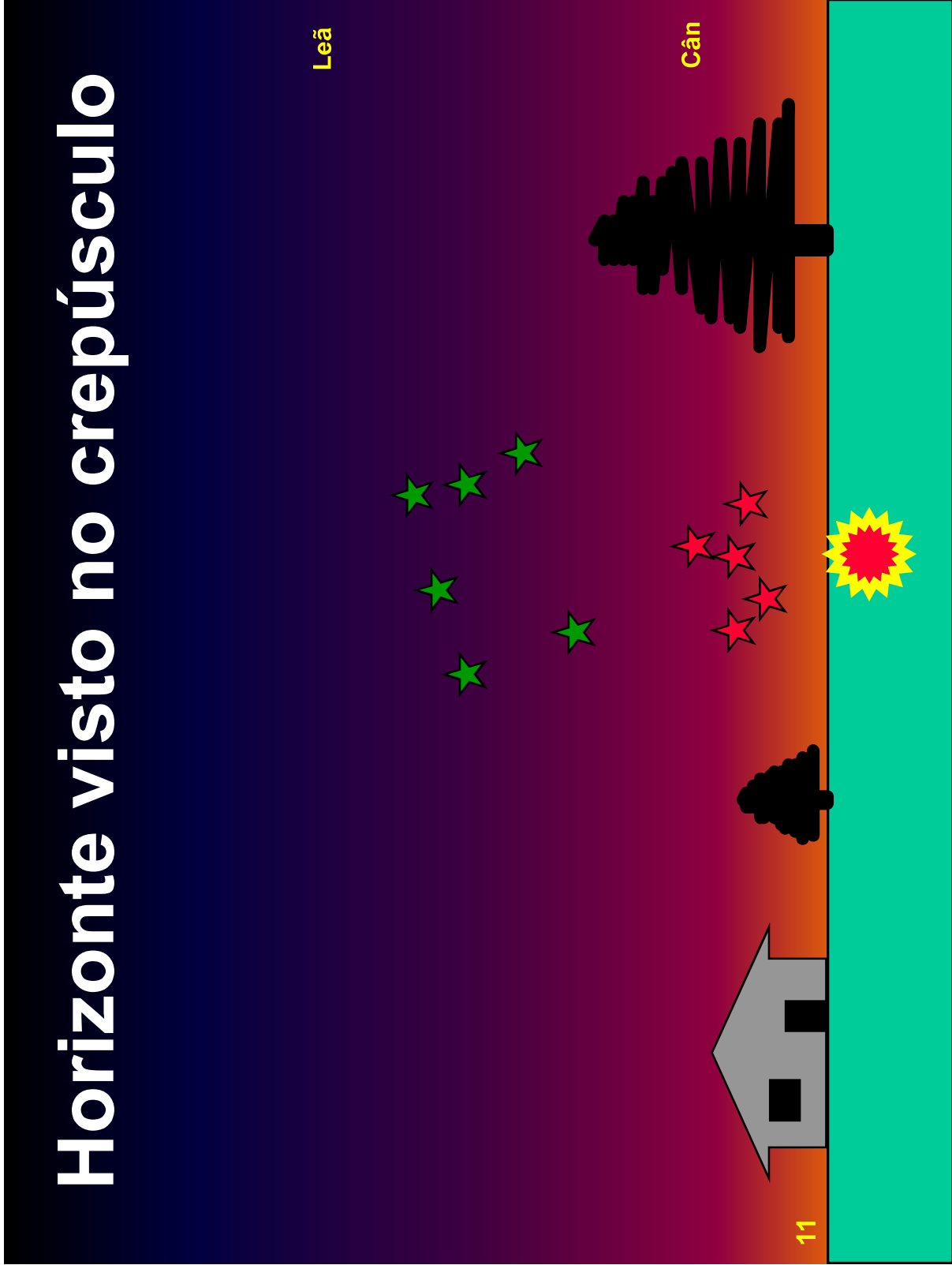


Horizonte visto no crepúsculo

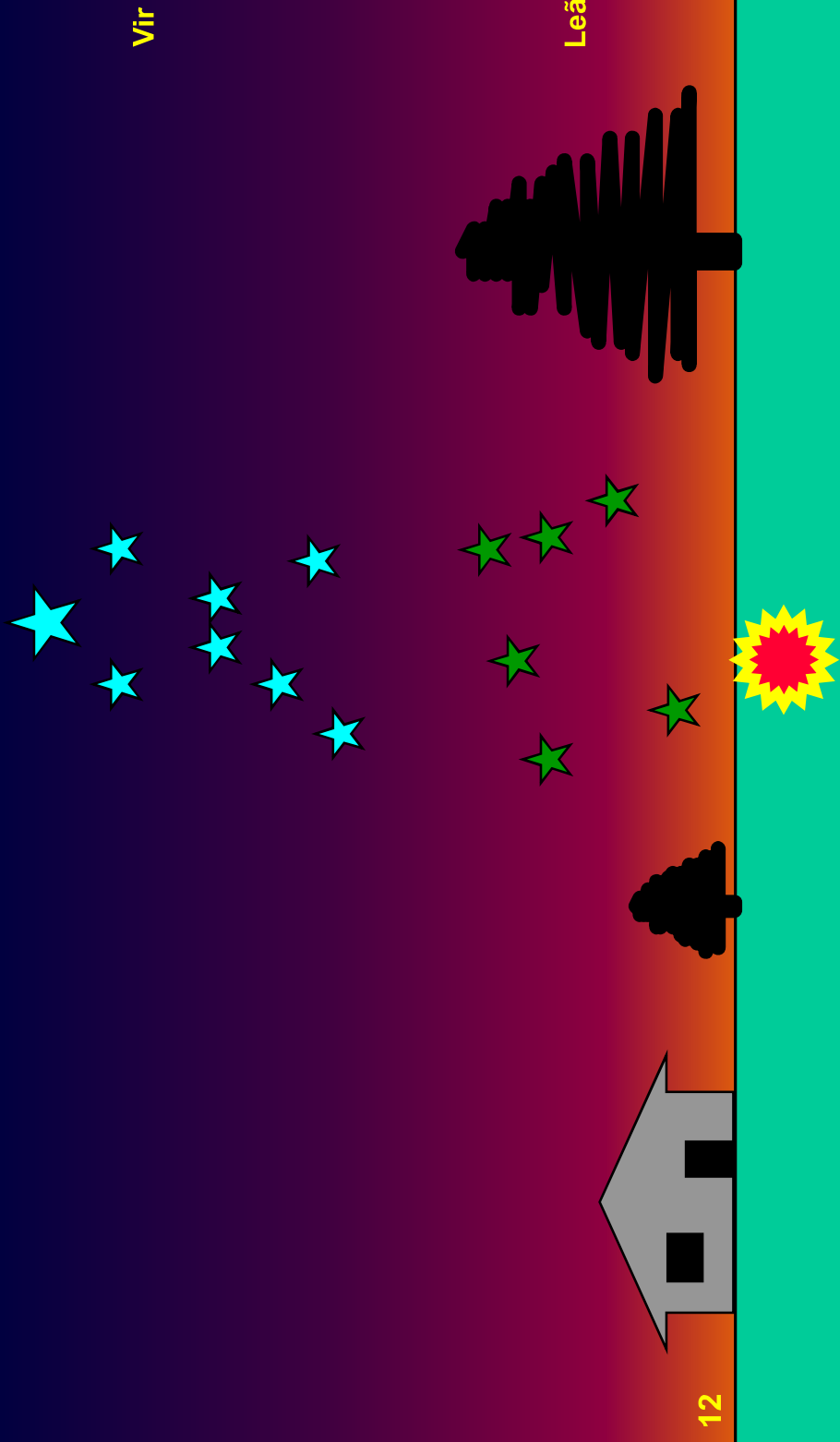
Leã

Cân

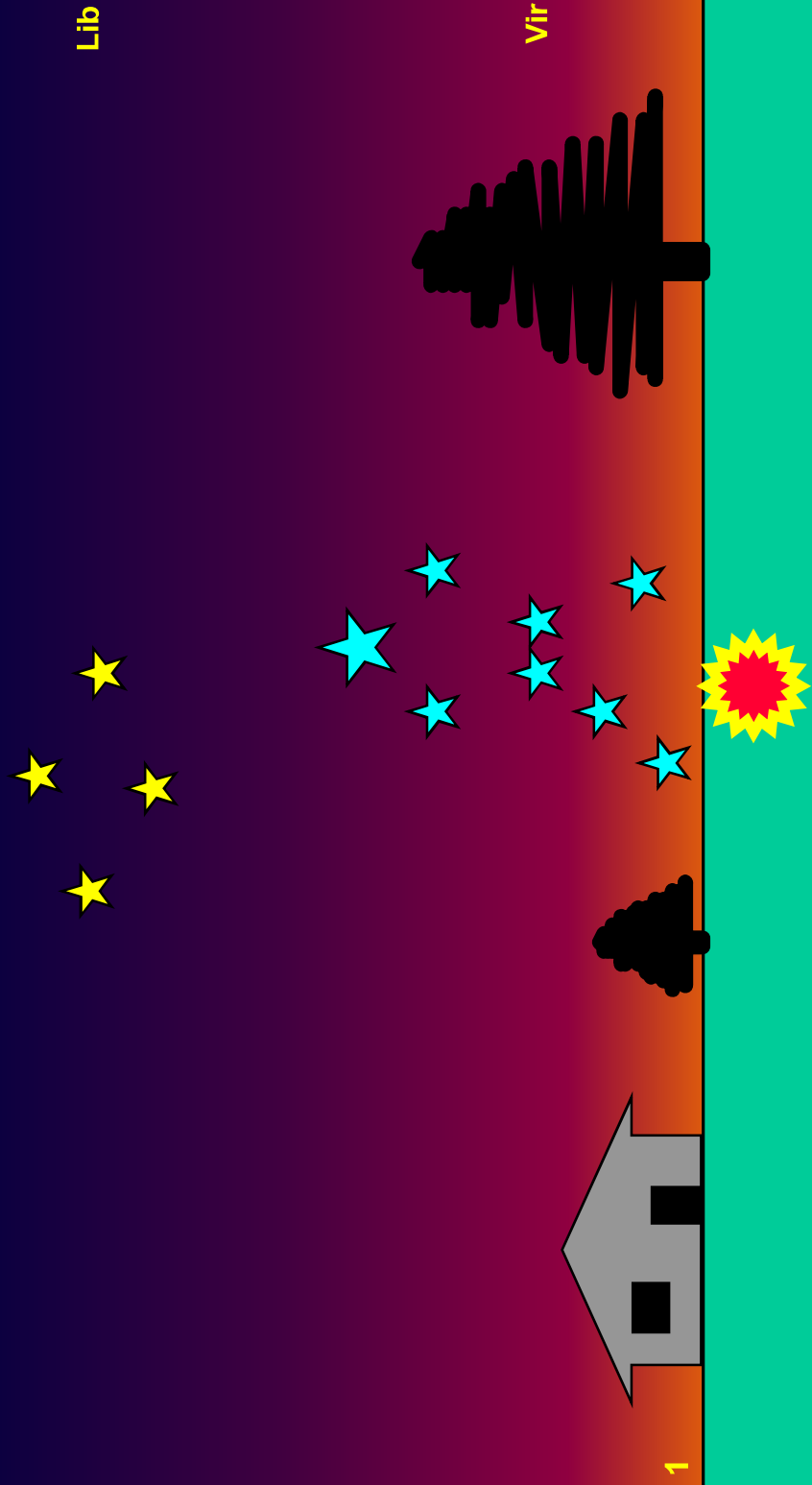
11



Horizonte visto no crepúsculo



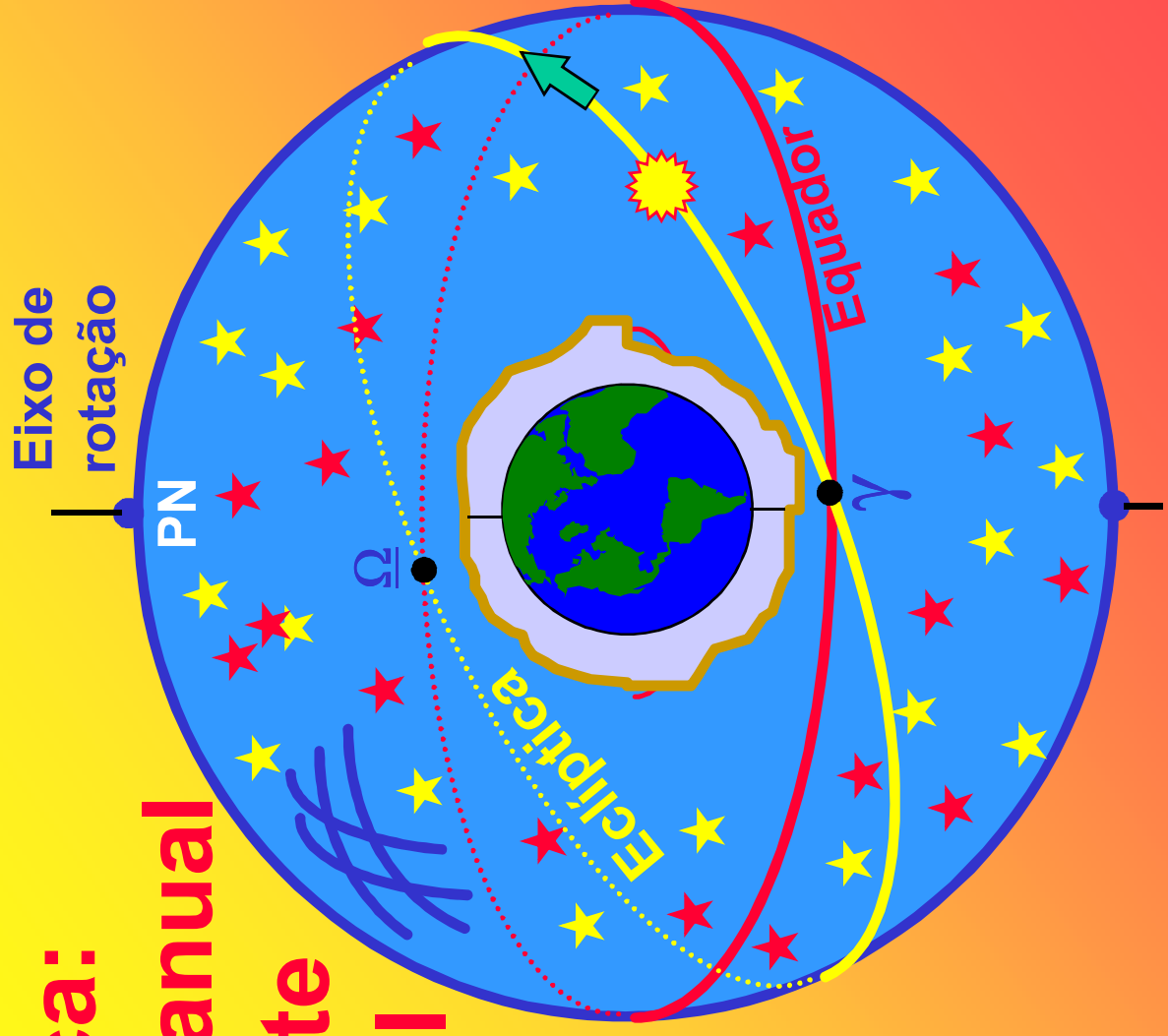
Horizonte visto no crepúsculo



Constelações e Signos Zodiacais



Eclíptica: Trajetória anual aparente do Sol



Evolução das idéias sobre a estrutura do Mundo

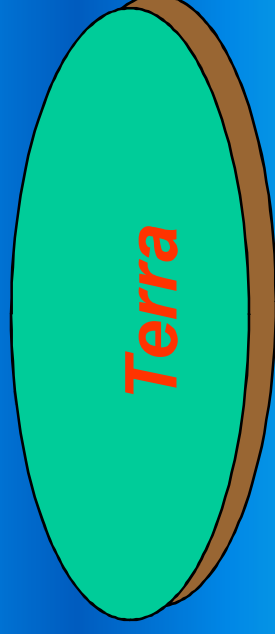
Akenaton

(sec XIV aC.)

**Heliocentrismo por
convicção religiosa !**

Tales

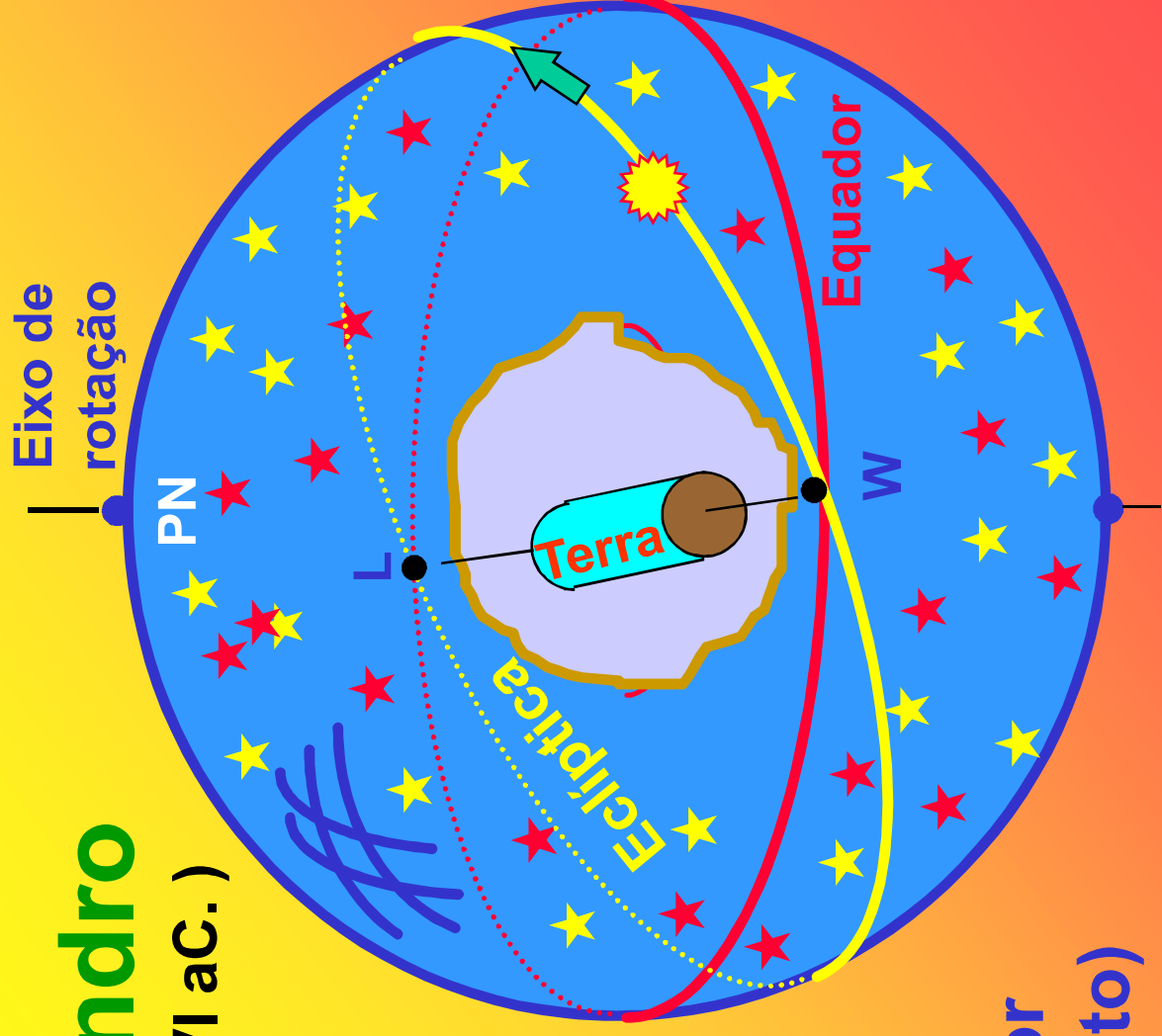
(Grego, séc. VI aC.)



A Terra é um disco chato num
Universo infinito de água

Anaximandro

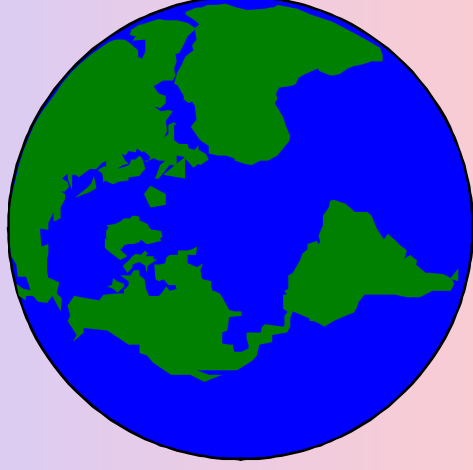
(Grego, séc. VI aC.)



Universo
composto por
ápeiron (infinito)

Pitágoras

(Grego, séc. VI a.C.)



Propôs de que a Terra fosse esférica

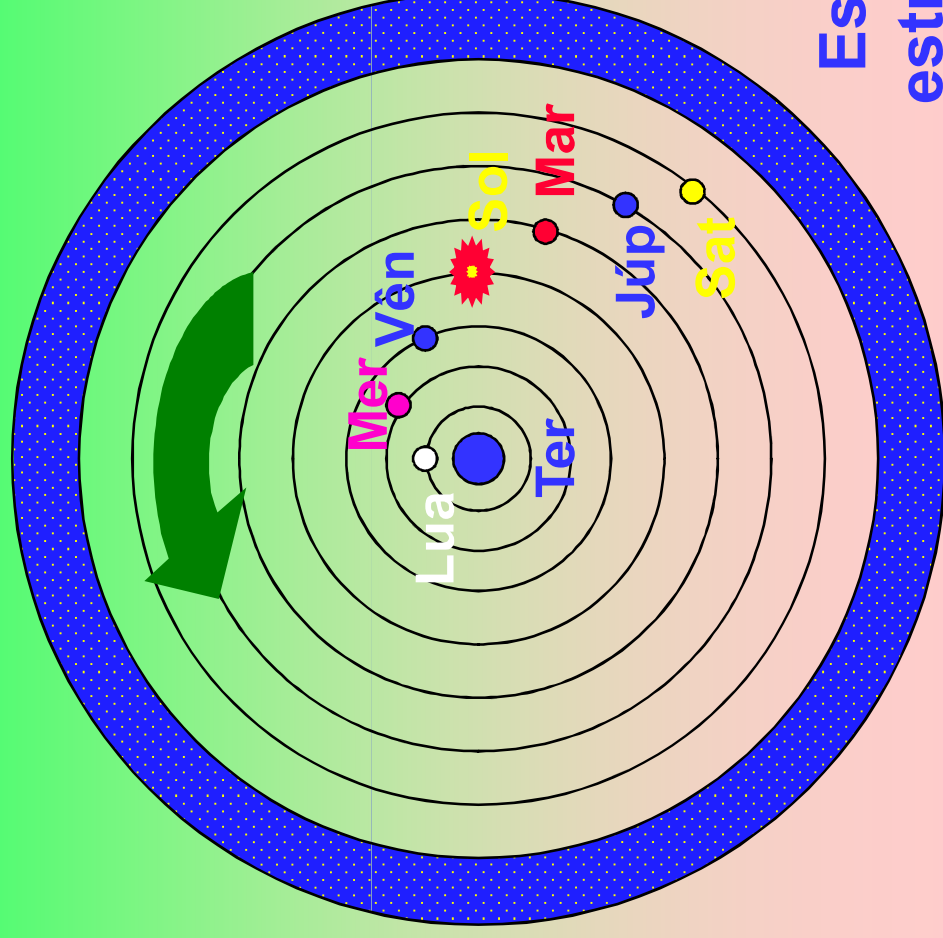
Aristóteles

(sec. IV aC.)

**Geocentrismo por
convicção filosófica!**

Sistema Geocêntrico

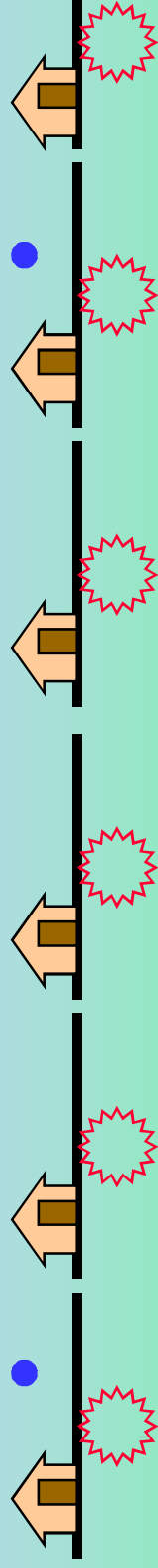
(Ptolomeu, séc. II)



Esfera das
estrelas fixas

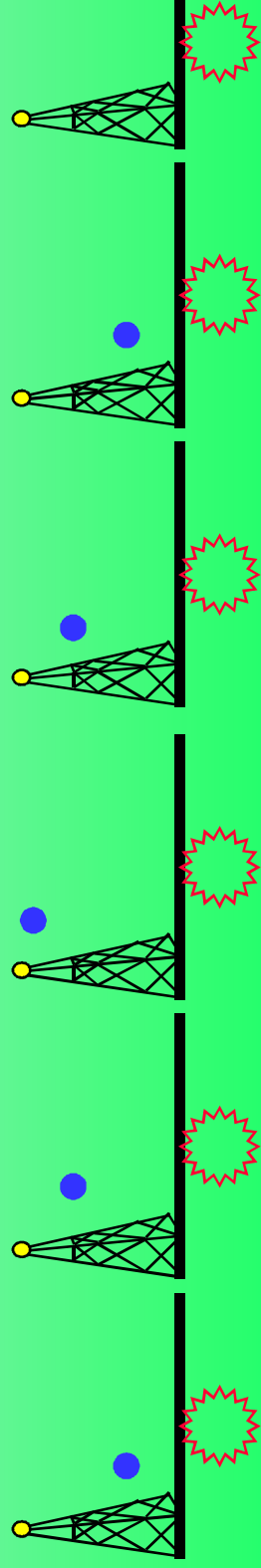
Posição de Mercúrio ou de Vênus em relação ao Sol

Vênus após o pôr-do-sol



Oeste

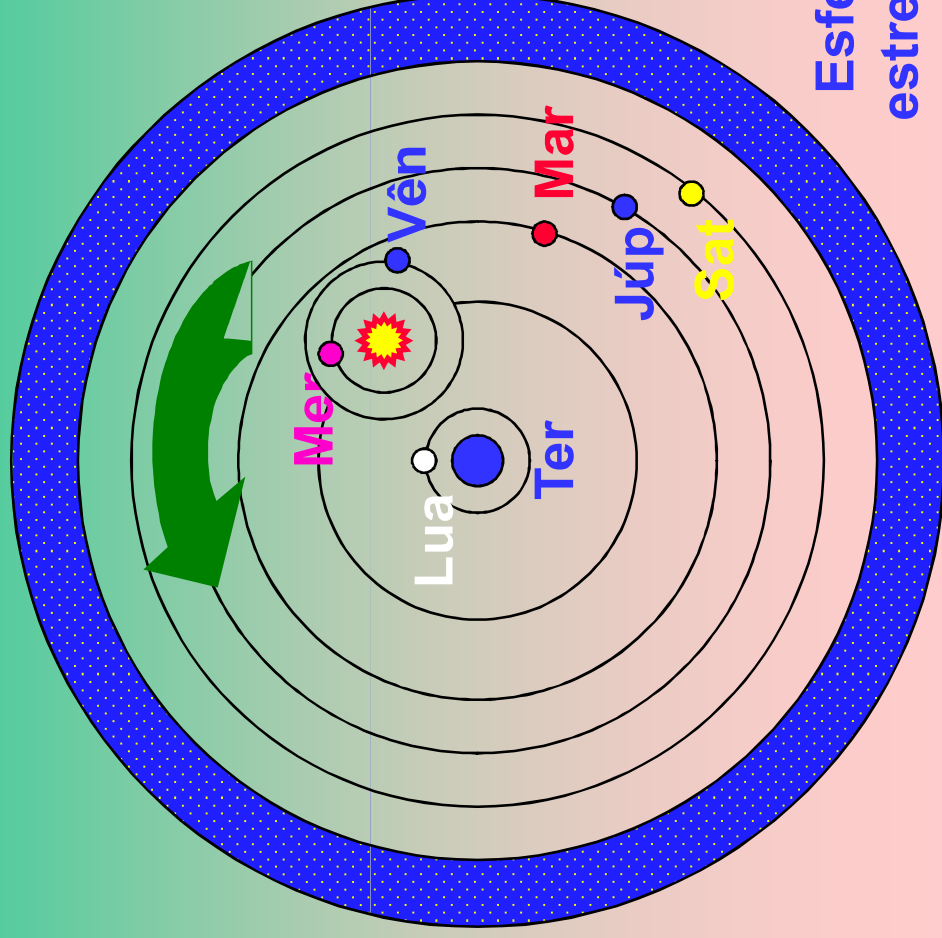
Vênus antes do nascer do Sol



Leste

Sistema Híbrido

(Heráclides, séc. IV a .C.)

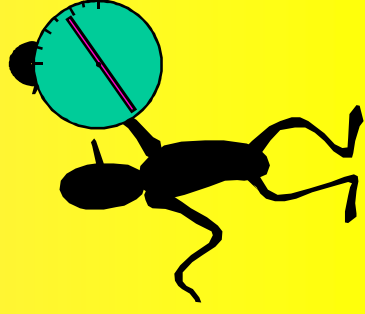
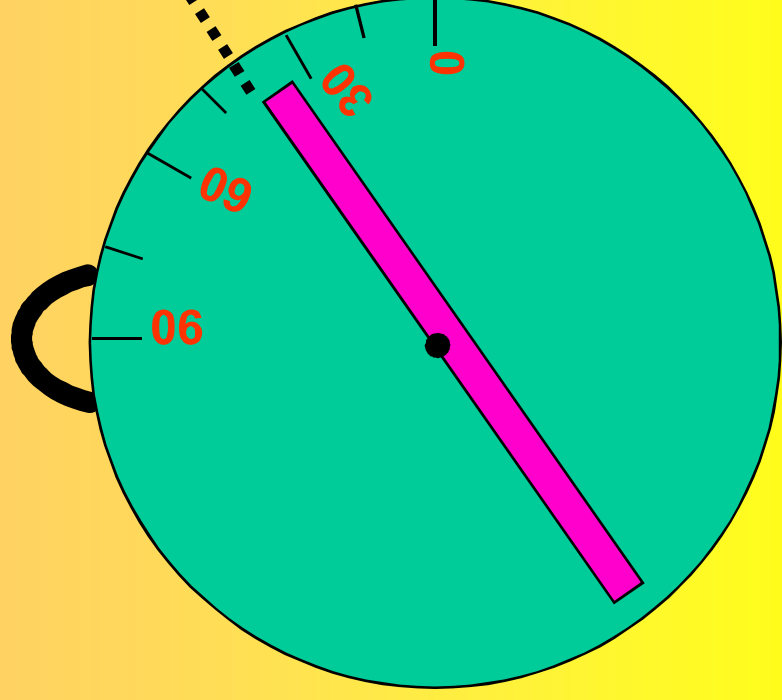


Esfera das
estrelas fixas

Outros instrumentos

Astrolábio

(Origem Babilônica)



Teoria versus Observação

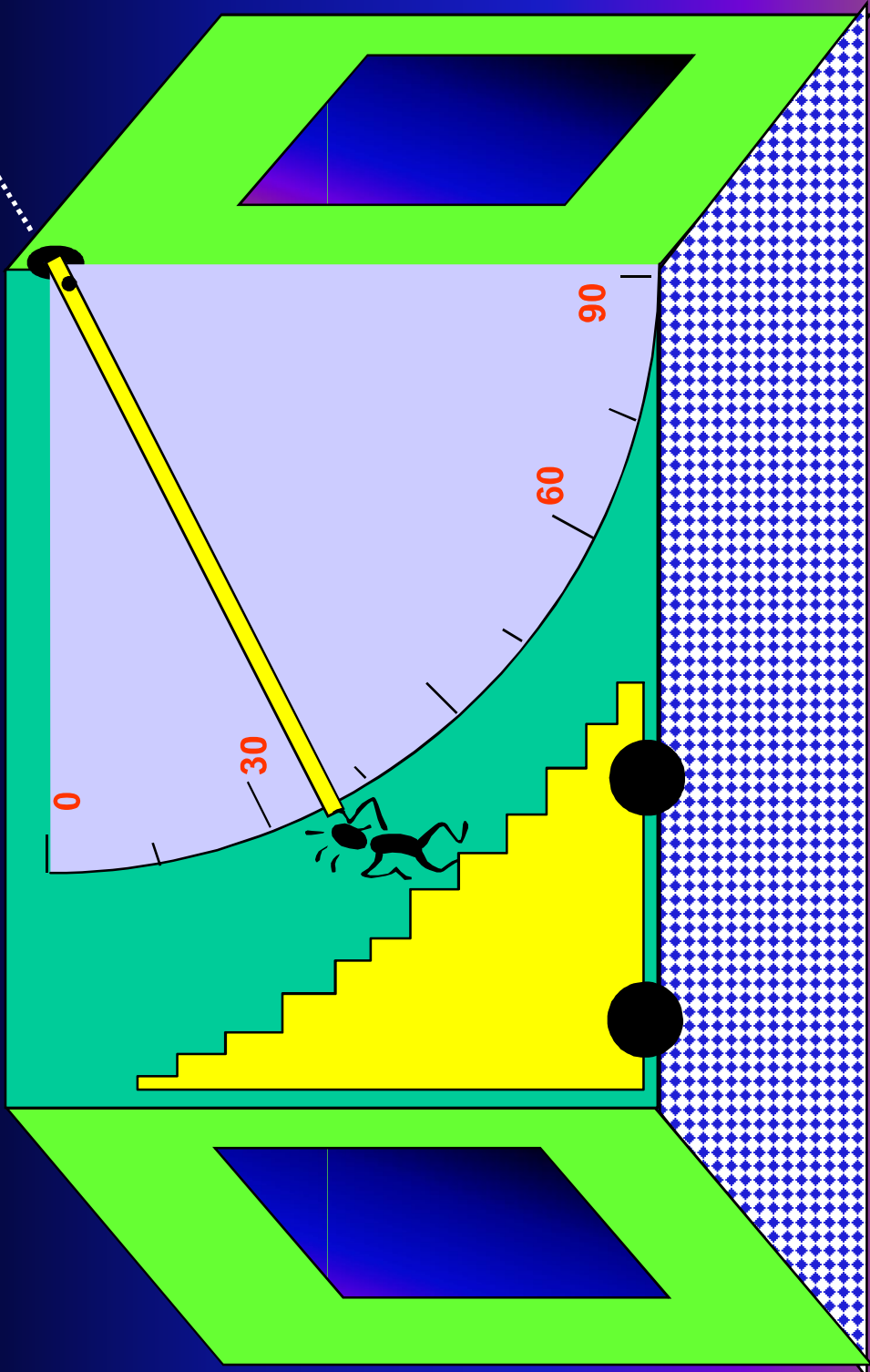


Calculei !
Estará lá !

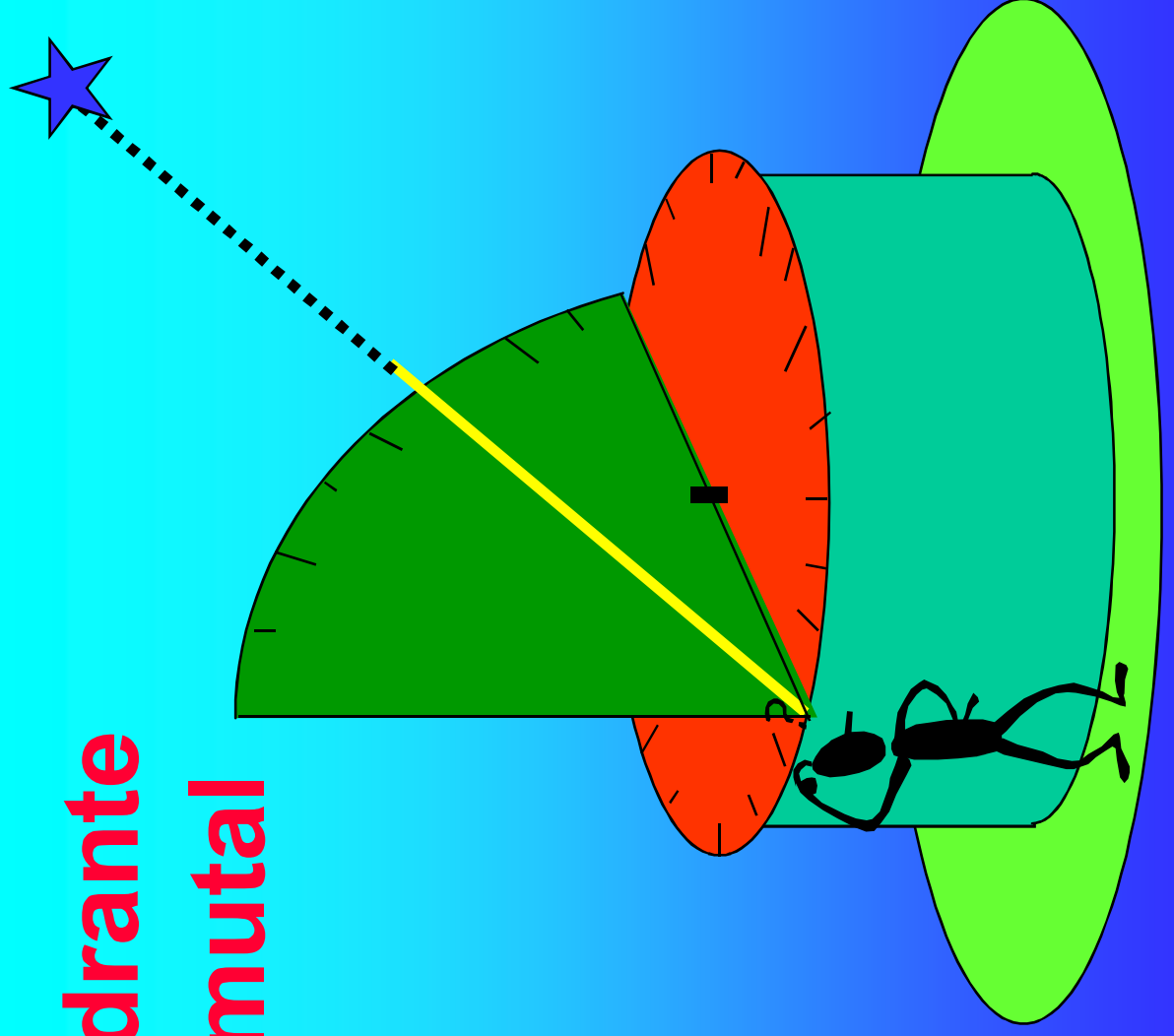
Erroooo !
Estou aquiiii !



Quadrante Mural

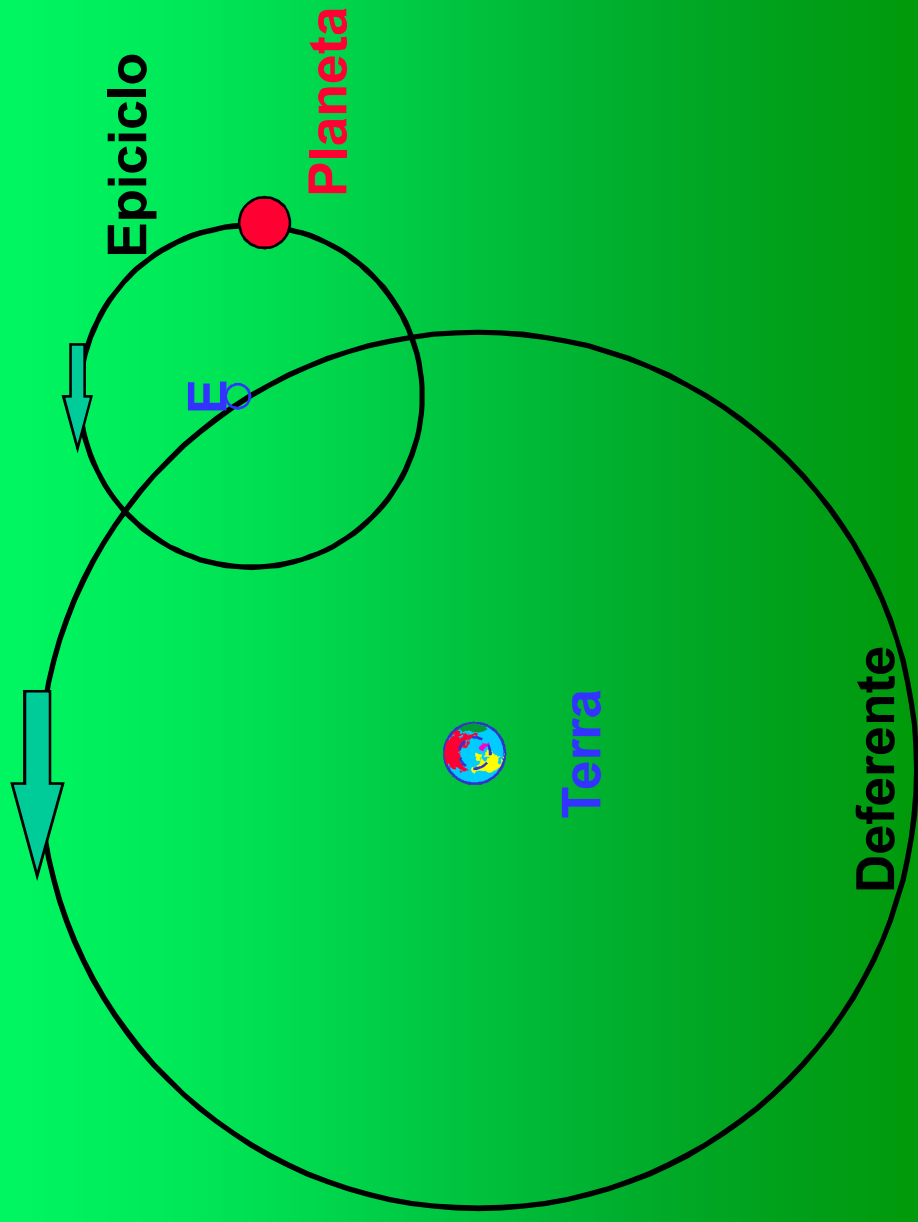


Quadrante Azimutal

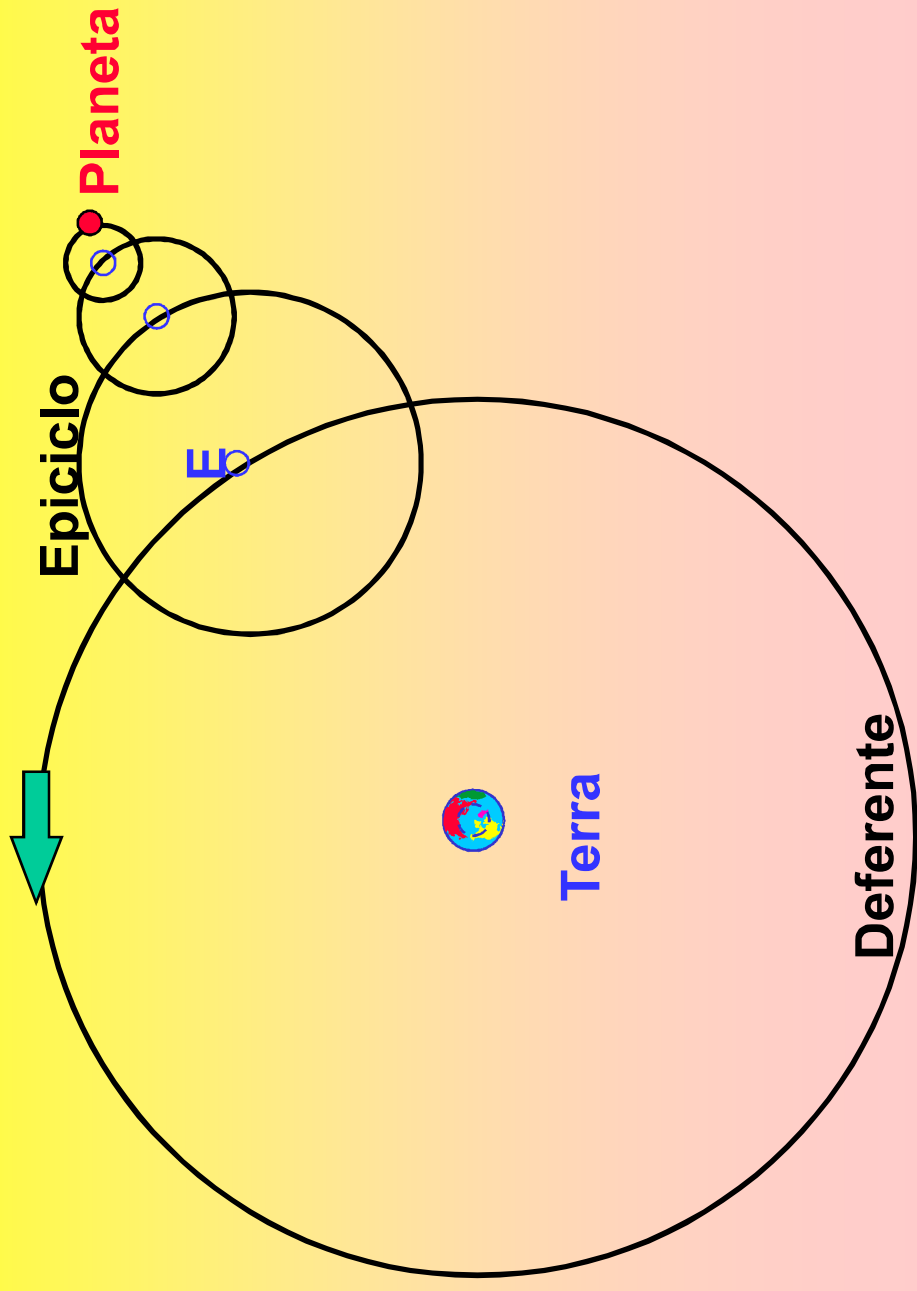


Sistema de Epiciclos

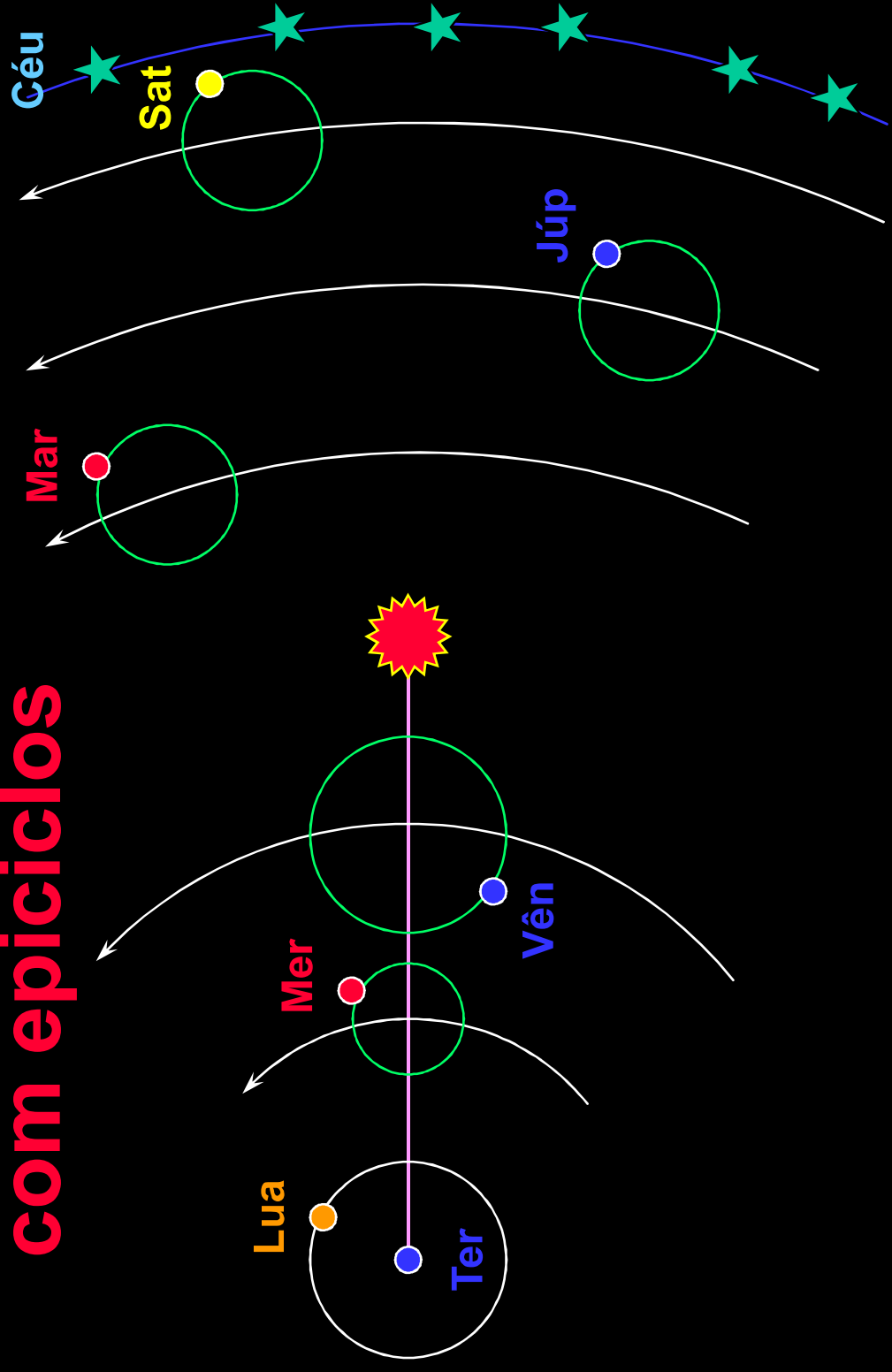
(Apolônio, séc. III a .C.)



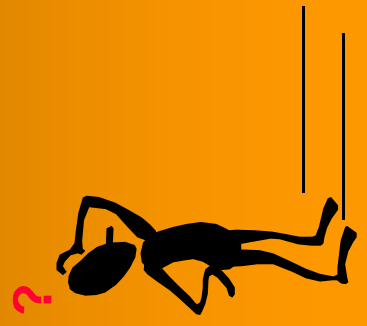
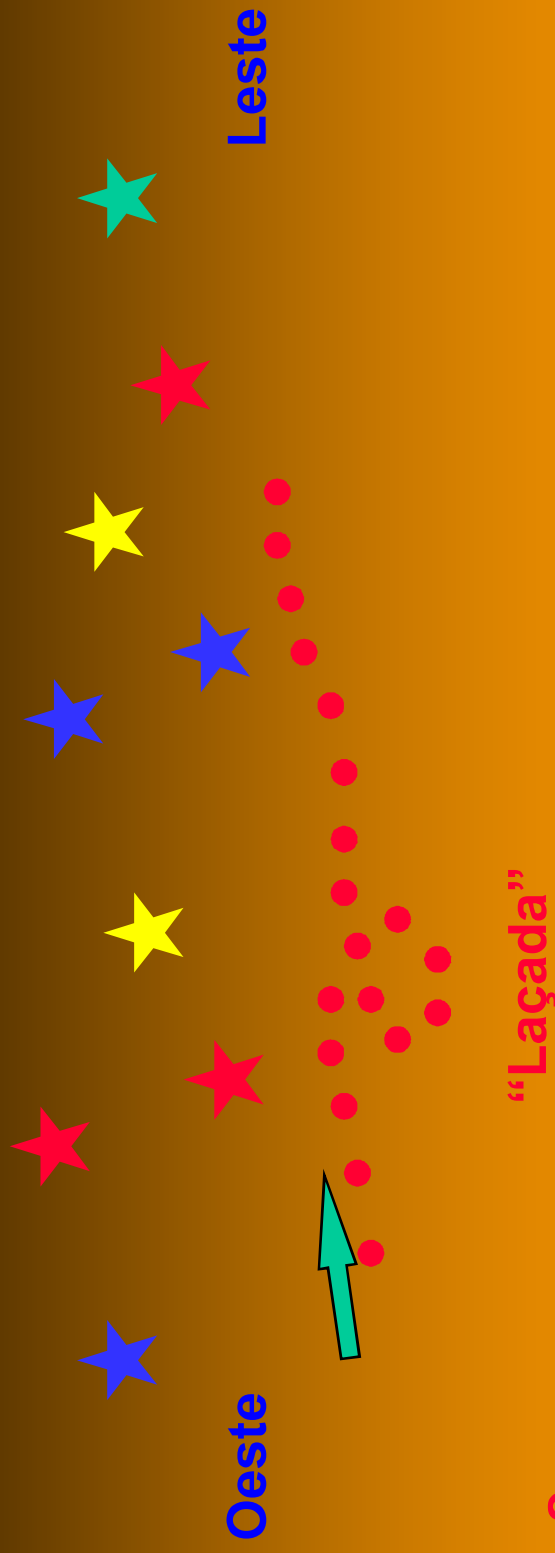
Sistema Complexo de Epiciclos



Geocentrismo com epiciclos

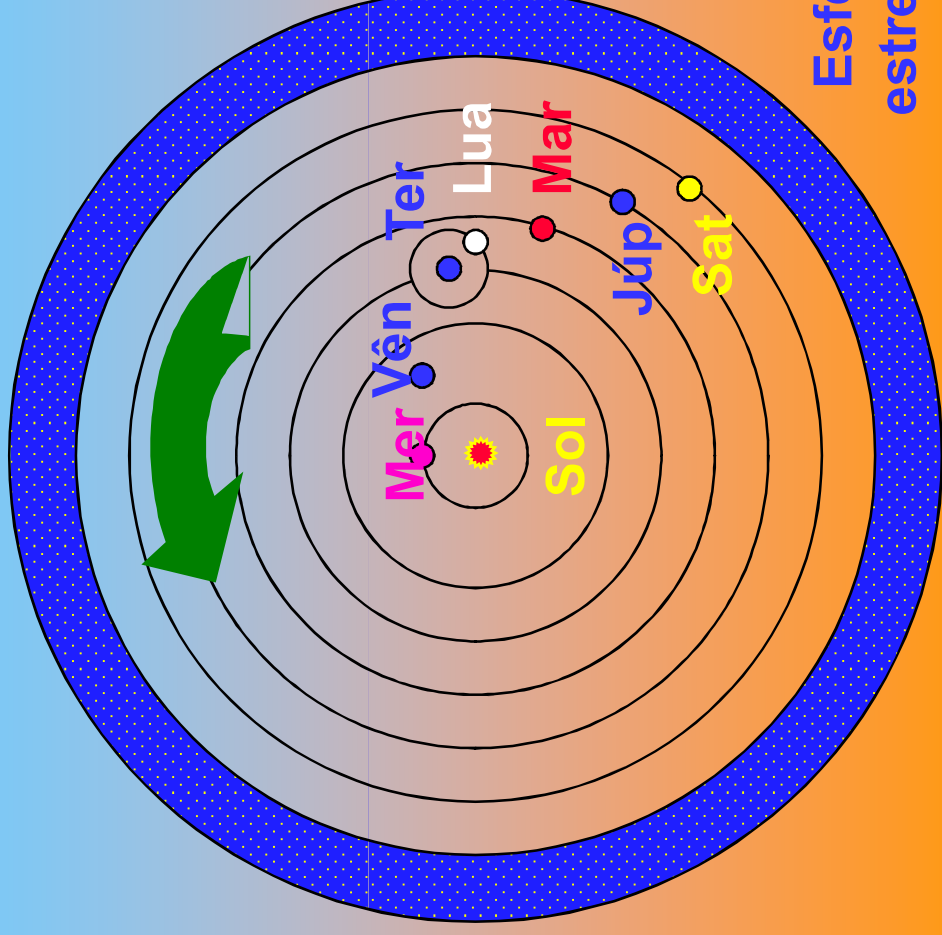


Movimento aparente não “perfeito”



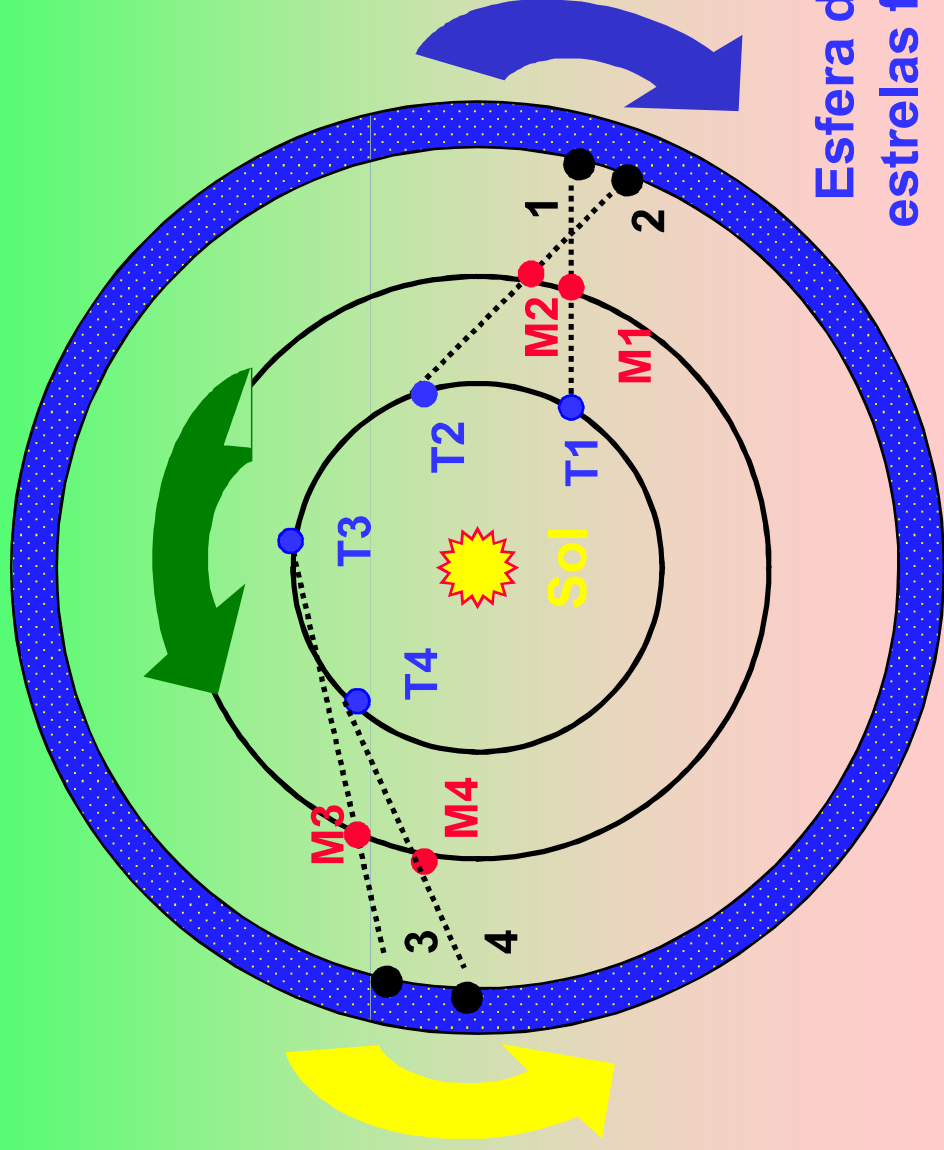
Sistema Heliocêntrico

(Copérnico, séc. XVI)



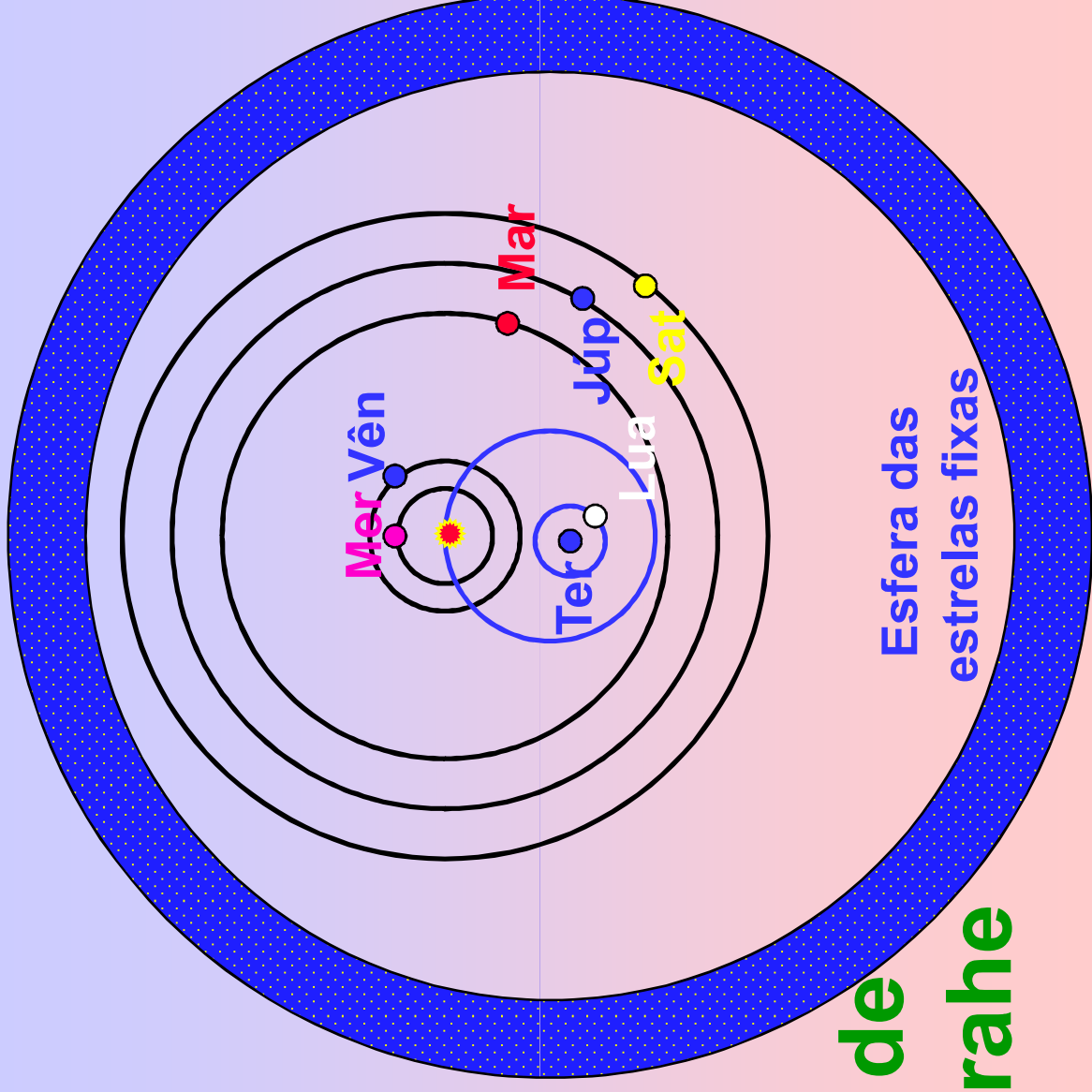
Esfera das
estrelas fixas

Explicação das “laçadas”



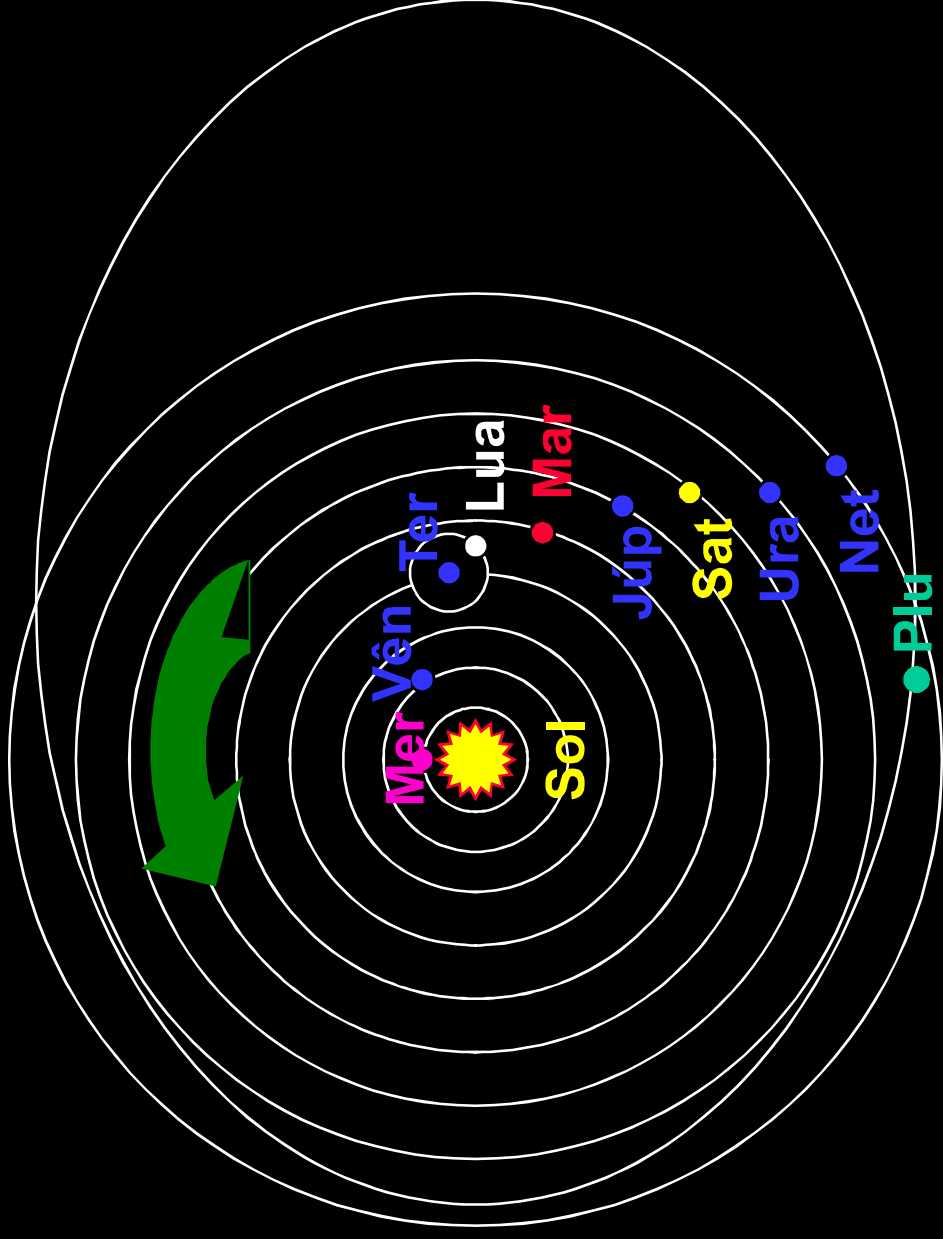
Esfera das
estrelas fixas

Sistema de Tycho Brahe (séc. XVI)

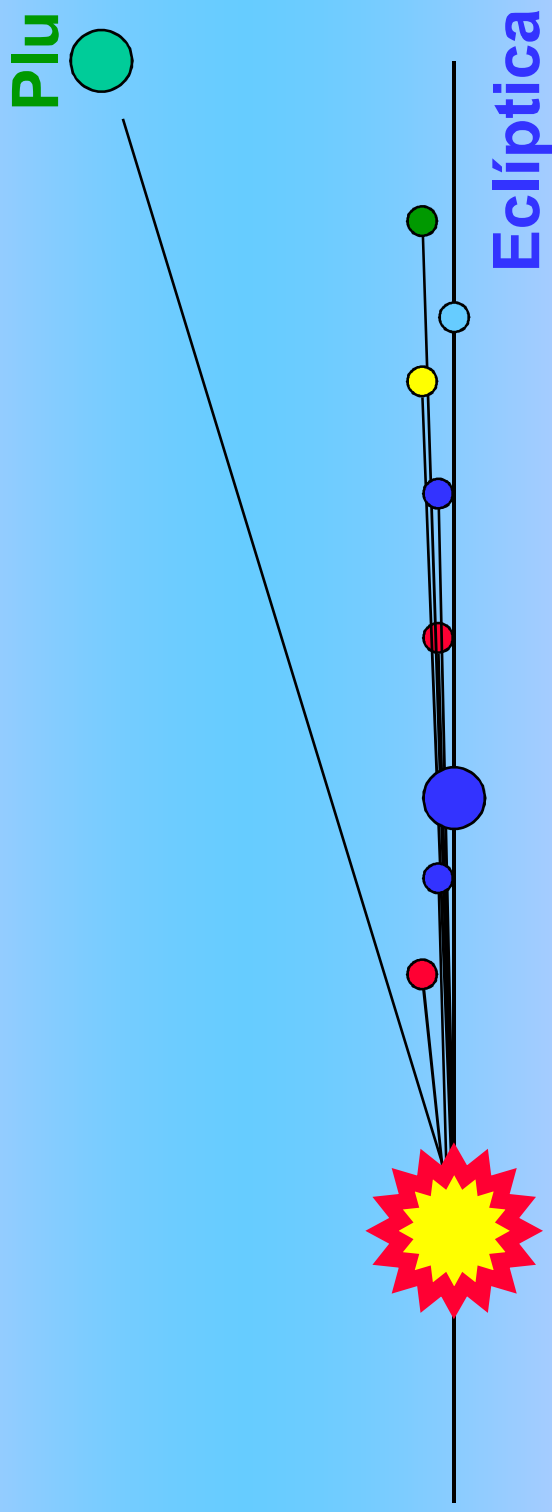


Estrutura atualmente conhecida do Sistema Solar

Sistema Heliocêntrico

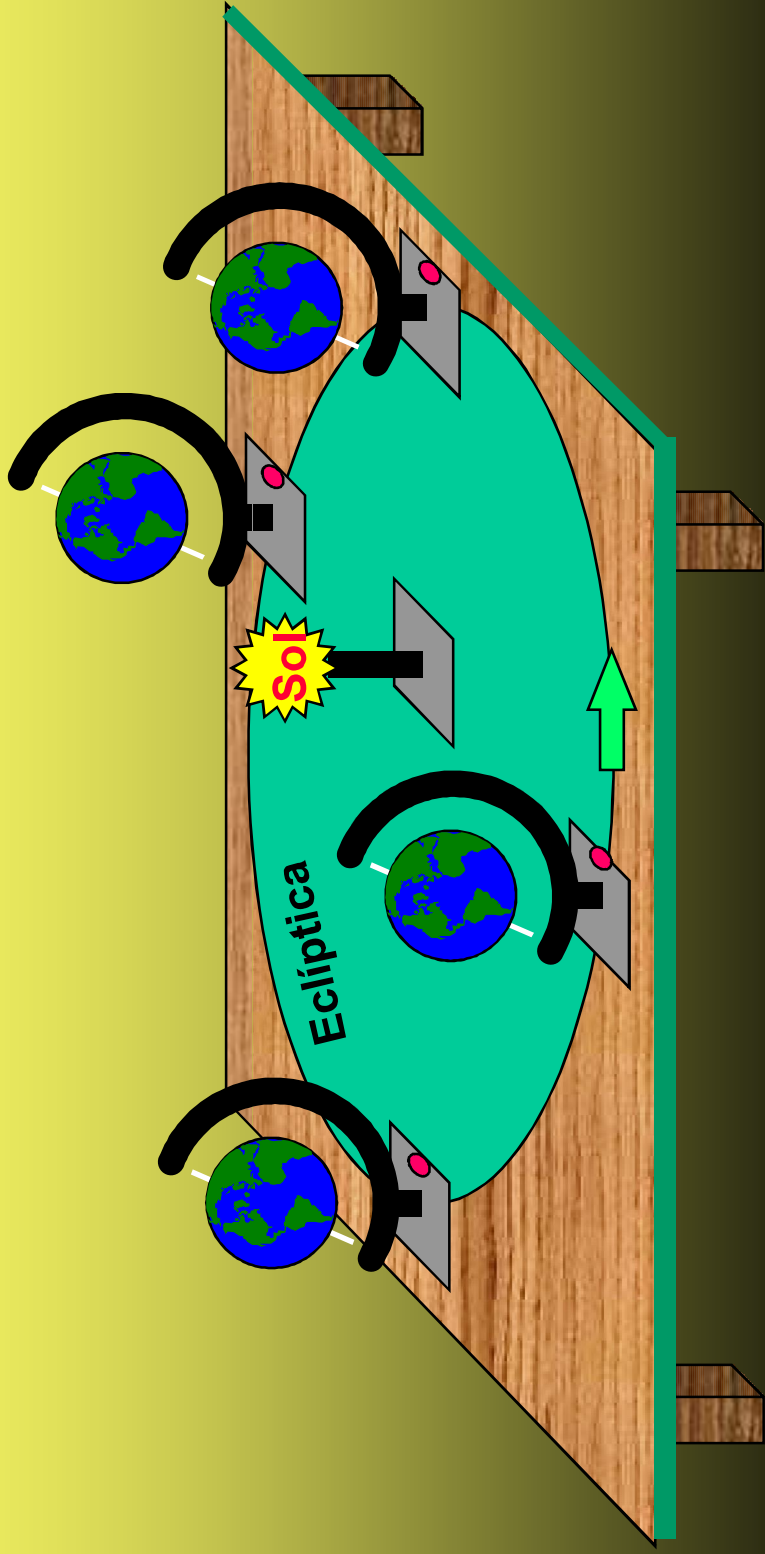


Órbitas não coplanares

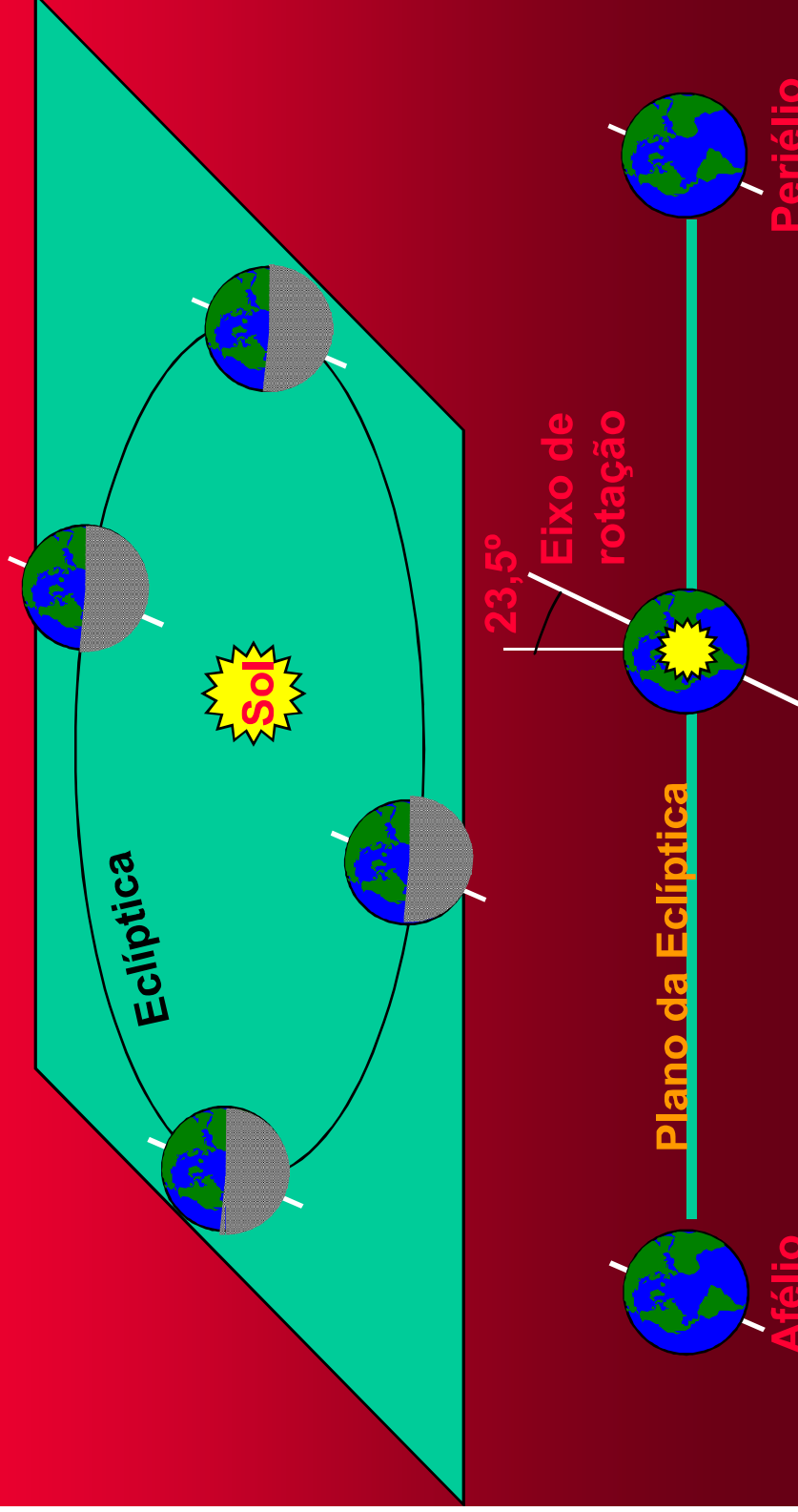


**Qual o motivo das
estações do ano?**

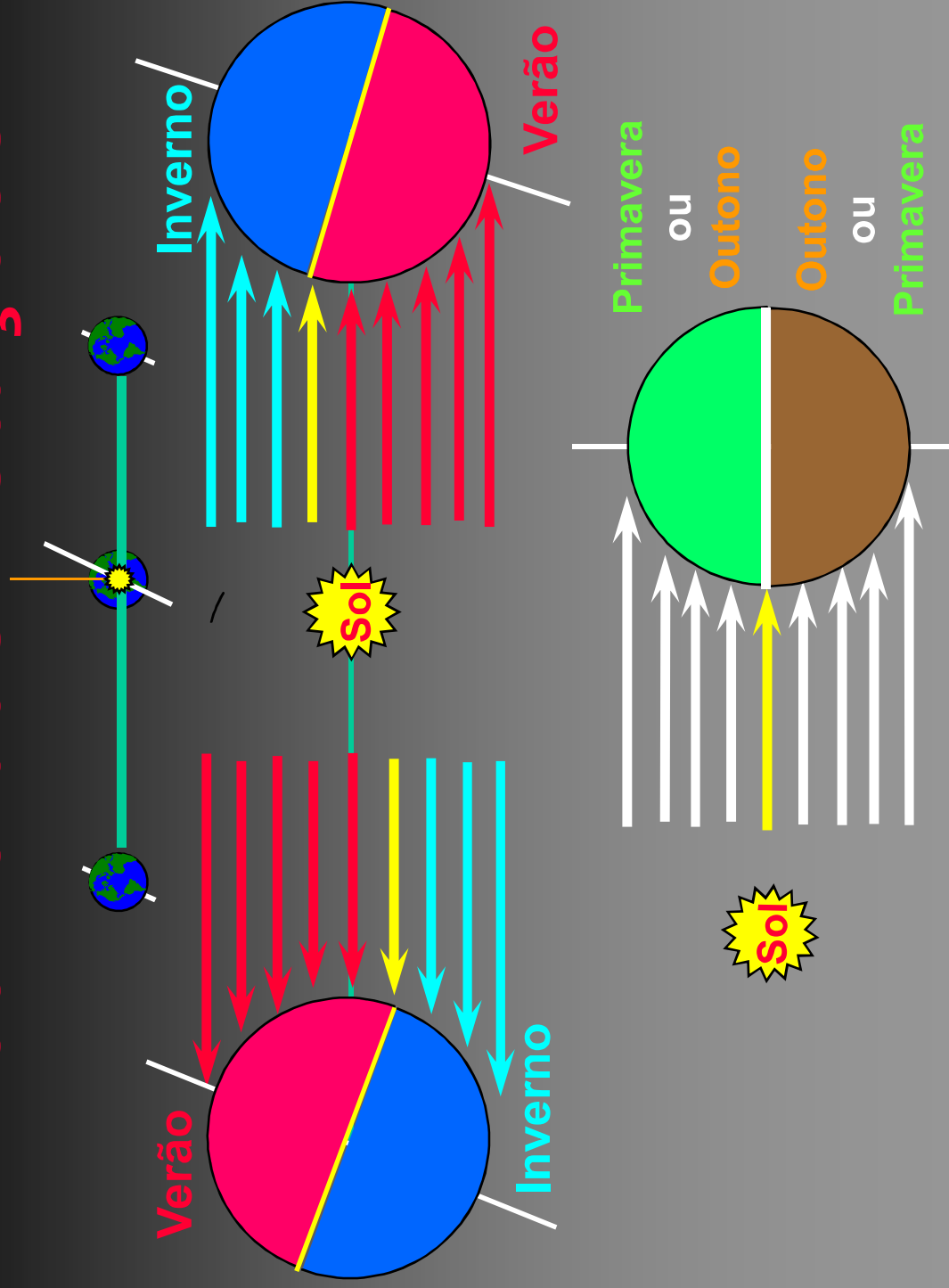
Órbita da Terra em torno do Sol



Órbita da Terra em torno do Sol

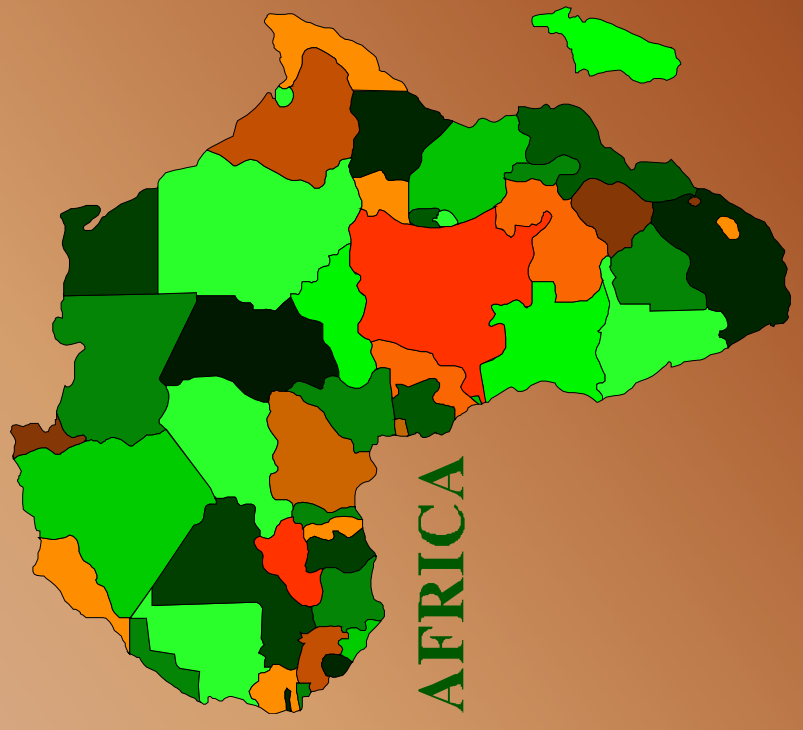


Motivo das Estações



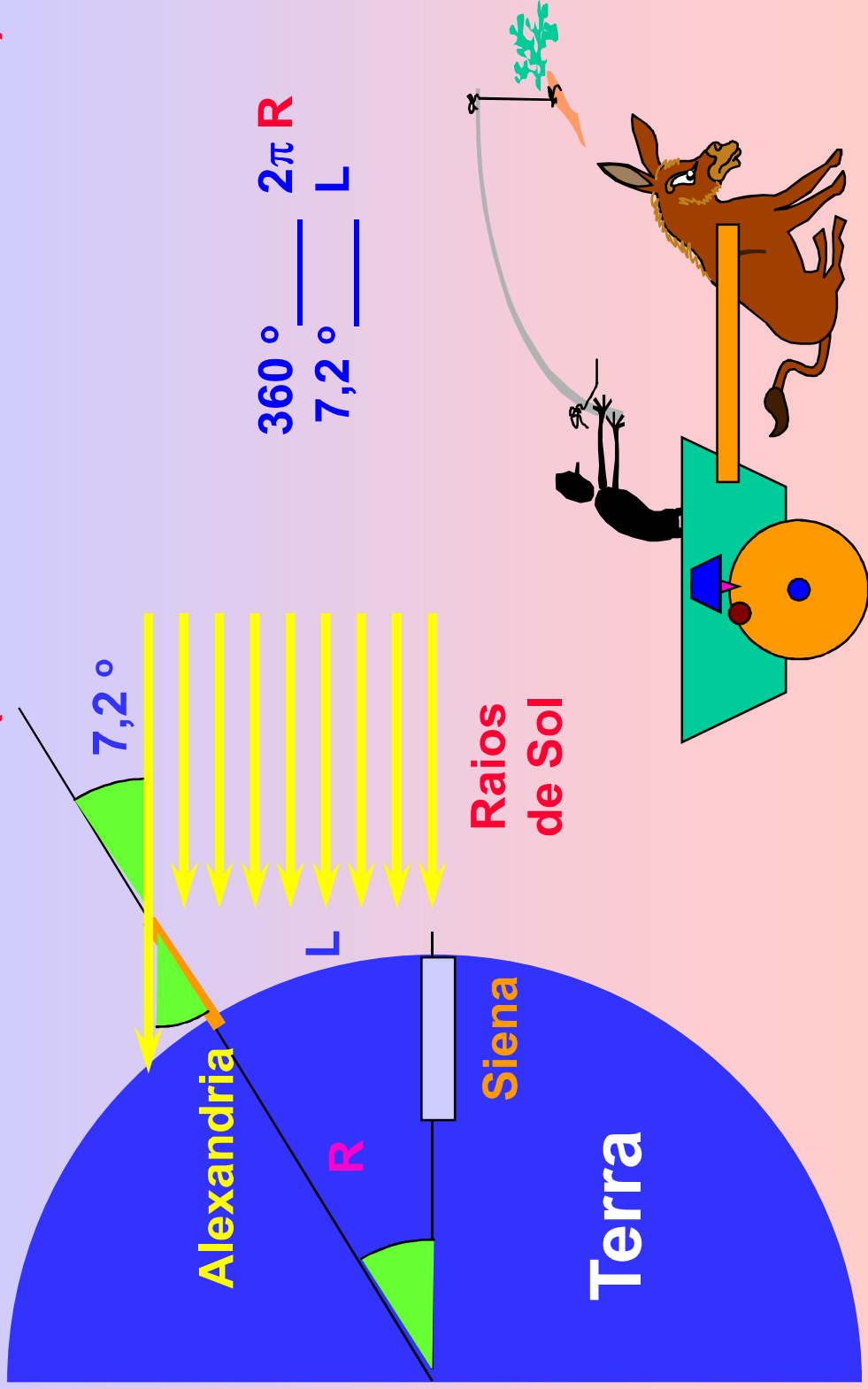
Distâncias no Sistema Solar

Egito

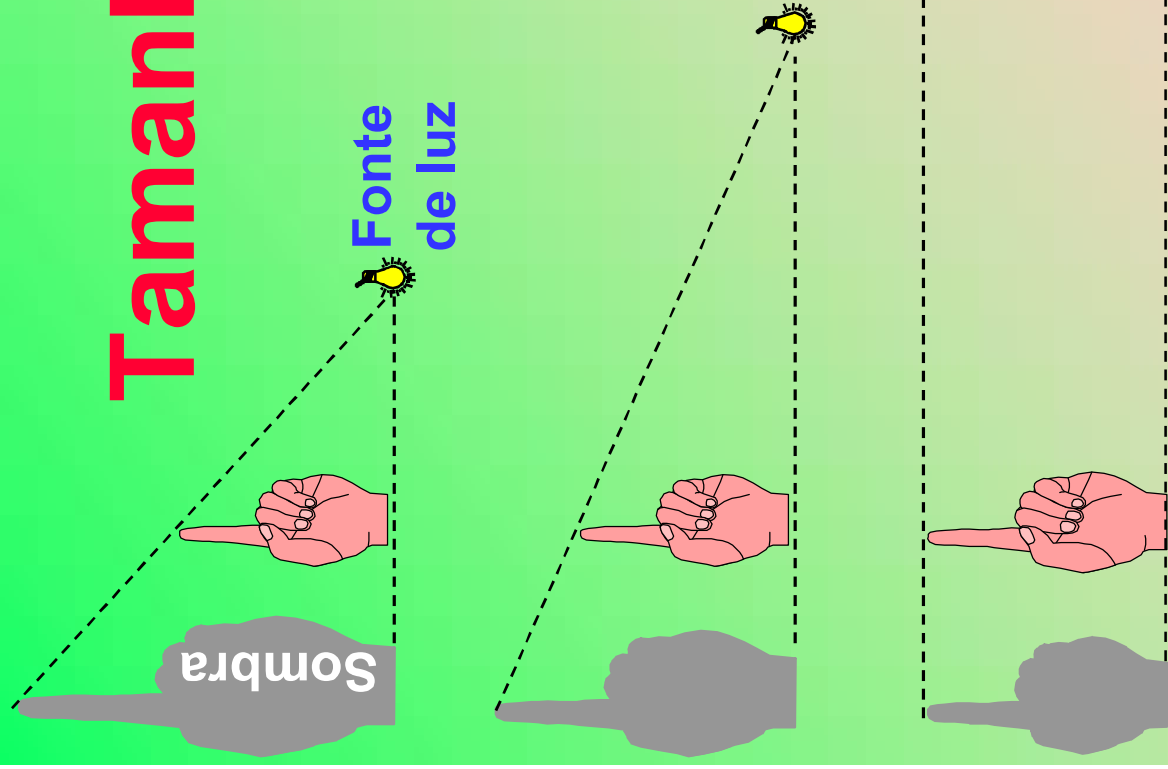


Raio da Terra

(Eratóstenes, séc. IV a .C.)



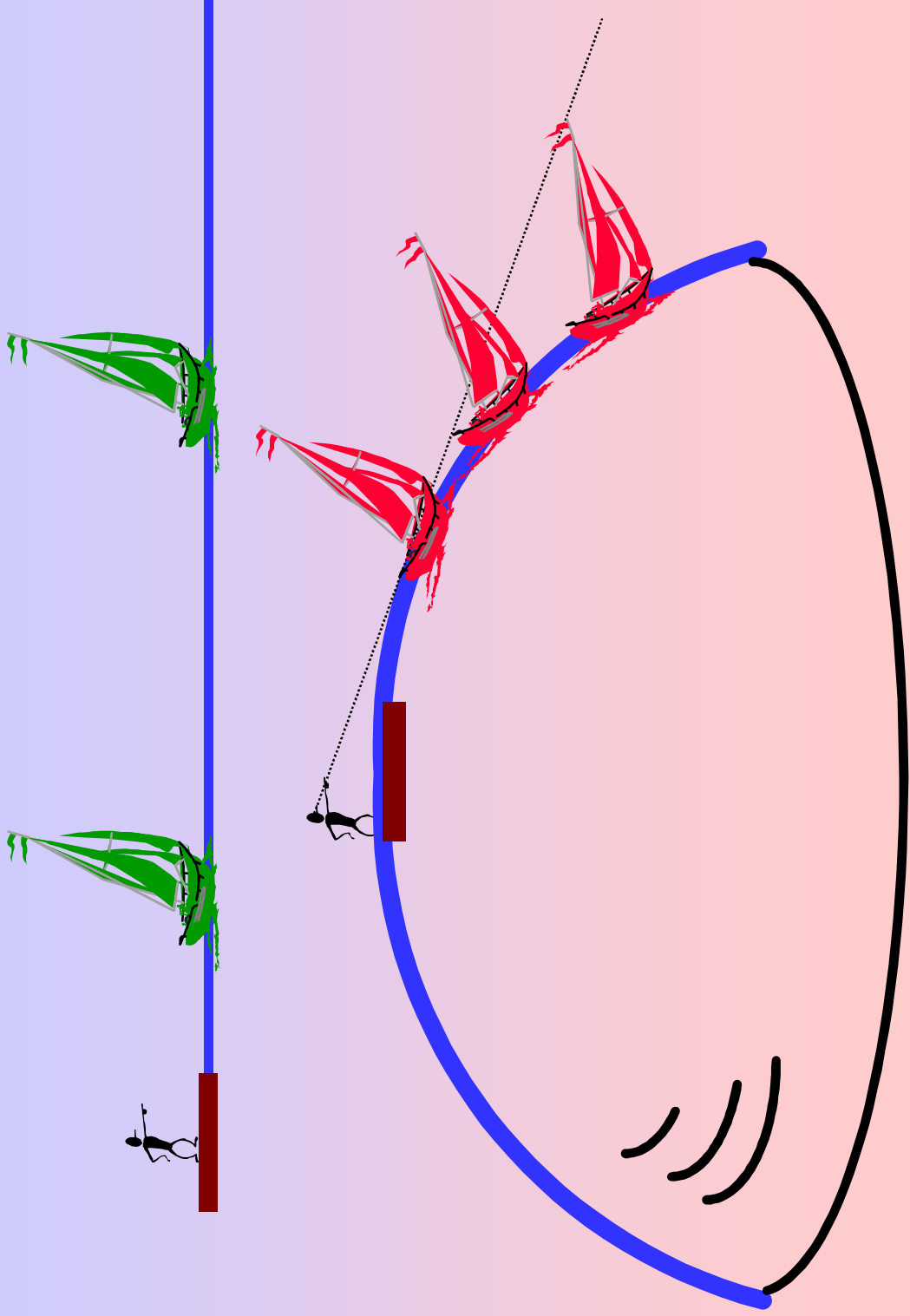
Tamanho da Sombra



Sombra em verdadeira
grandeza exige que a
fonte esteja no infinito.

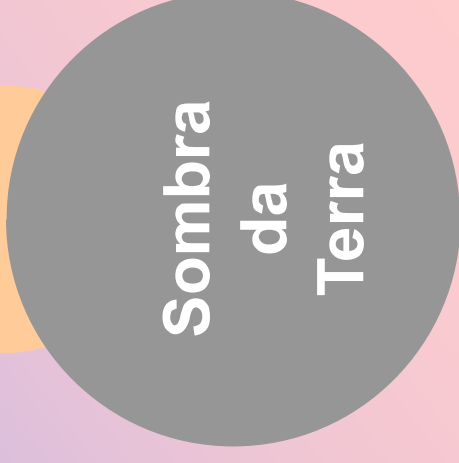
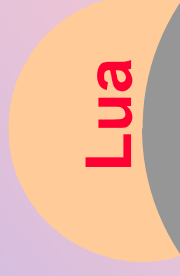
**Mas... já se sabia que a
Terra era esférica naquela
época?**

Esfericidade da Terra



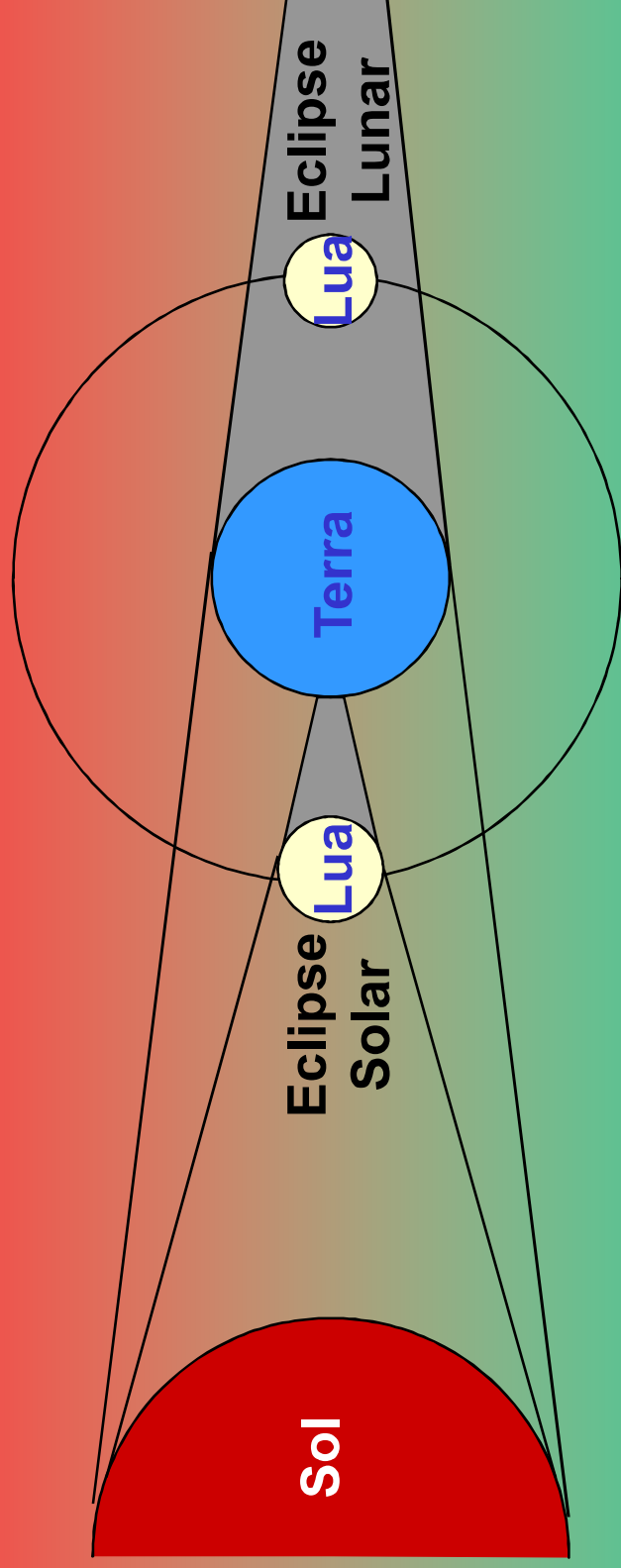
Esfericidade da Terra

(Durante um Eclipse Lunar)

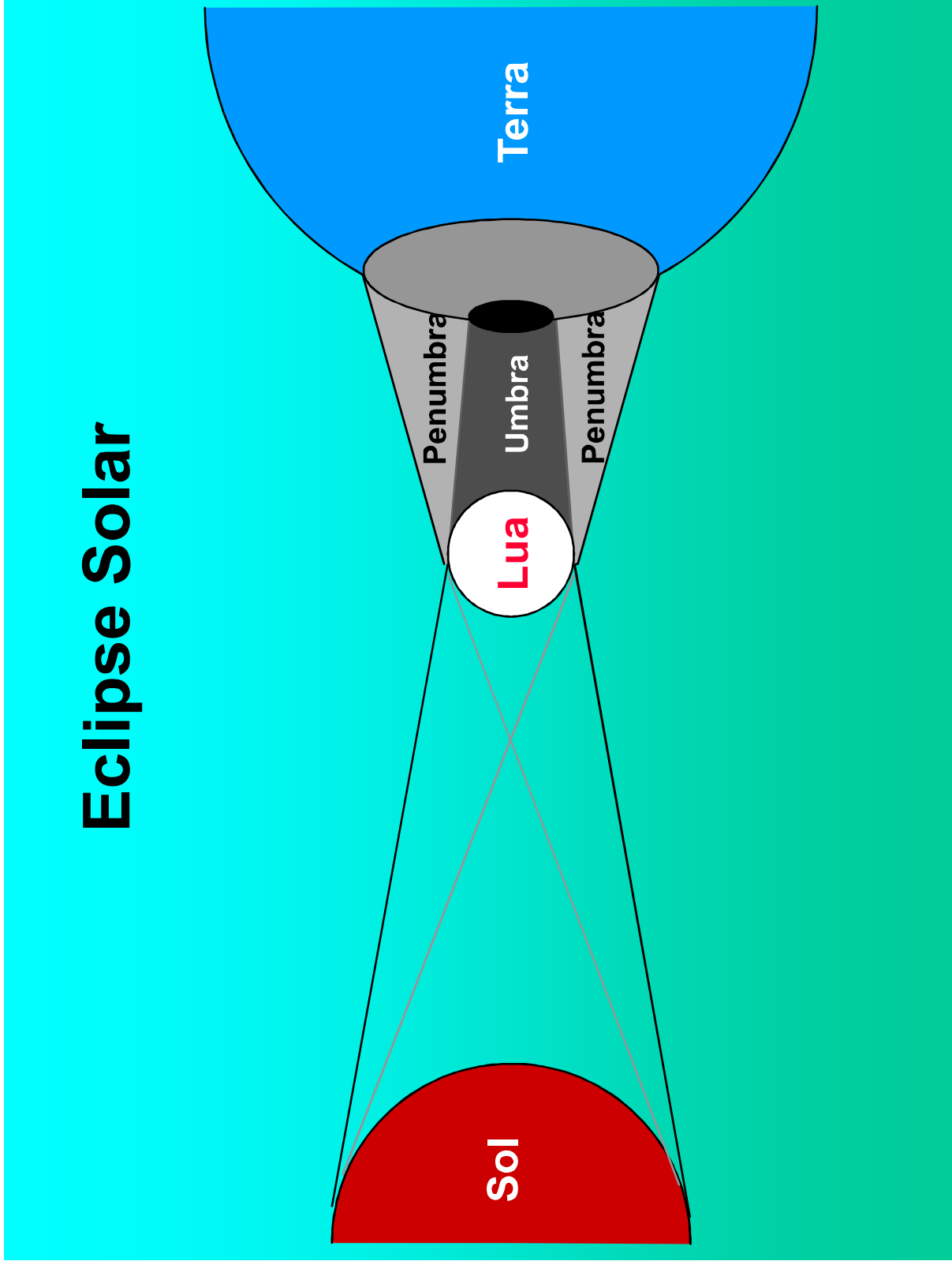


Eclipses

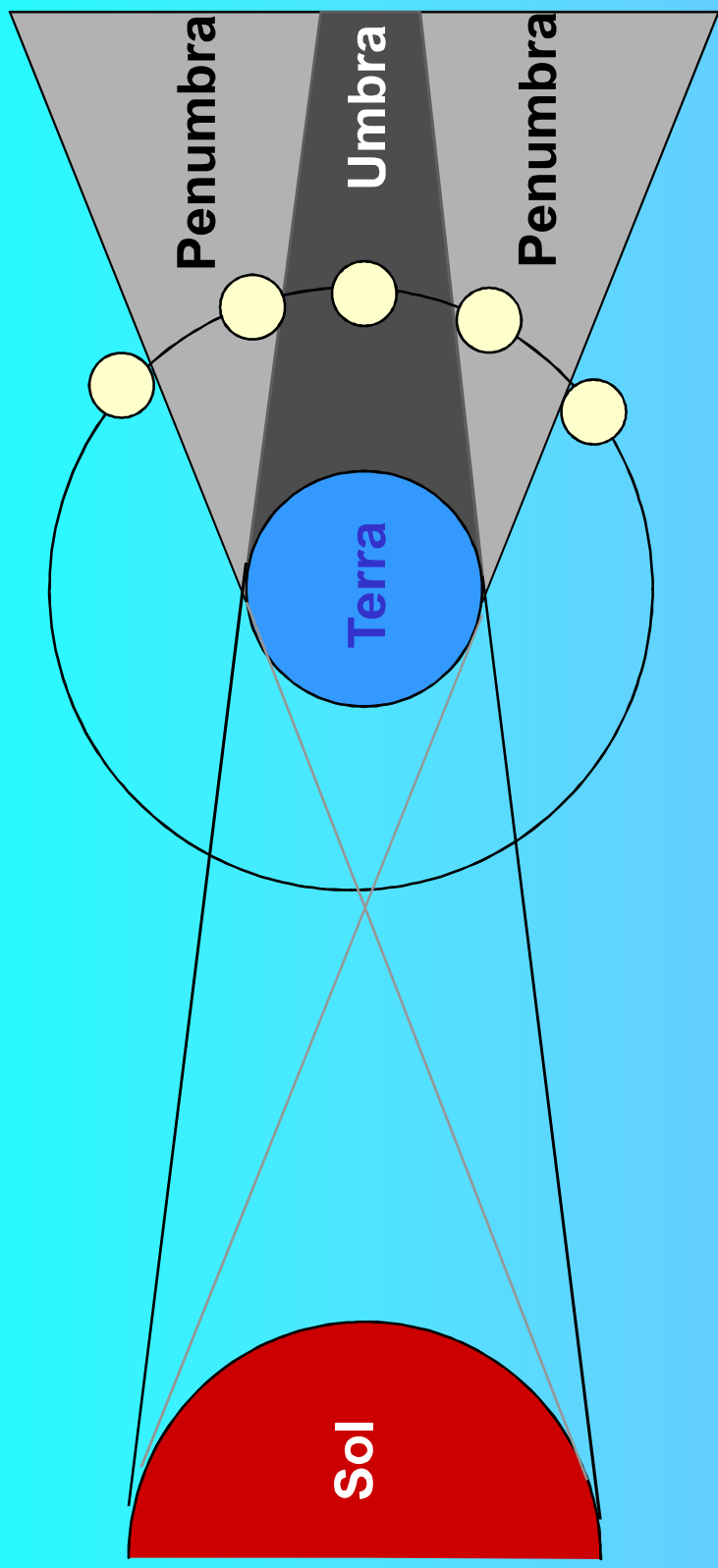
Tipos de Eclipses



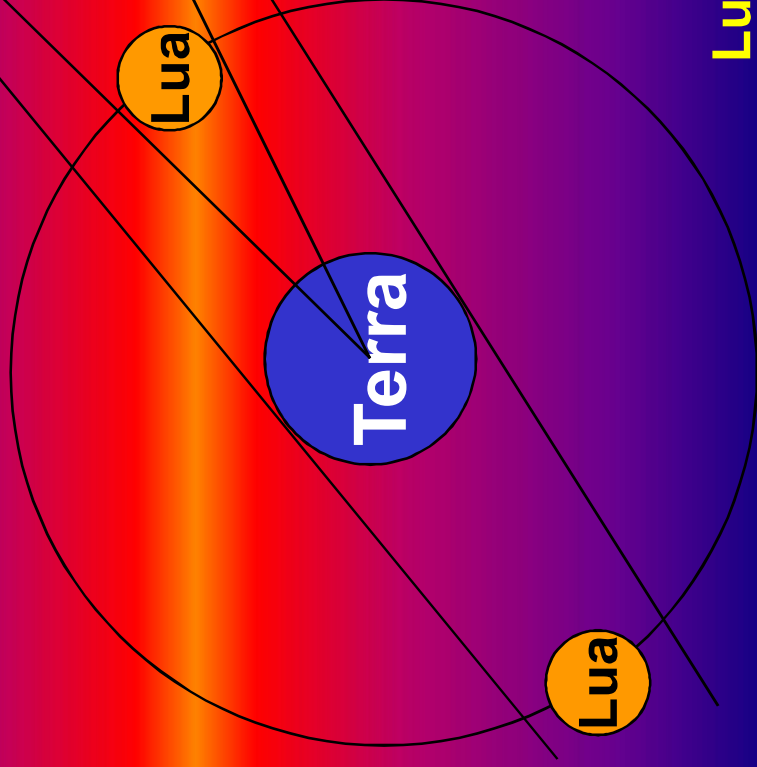
Eclipse Solar



Eclipse Lunar

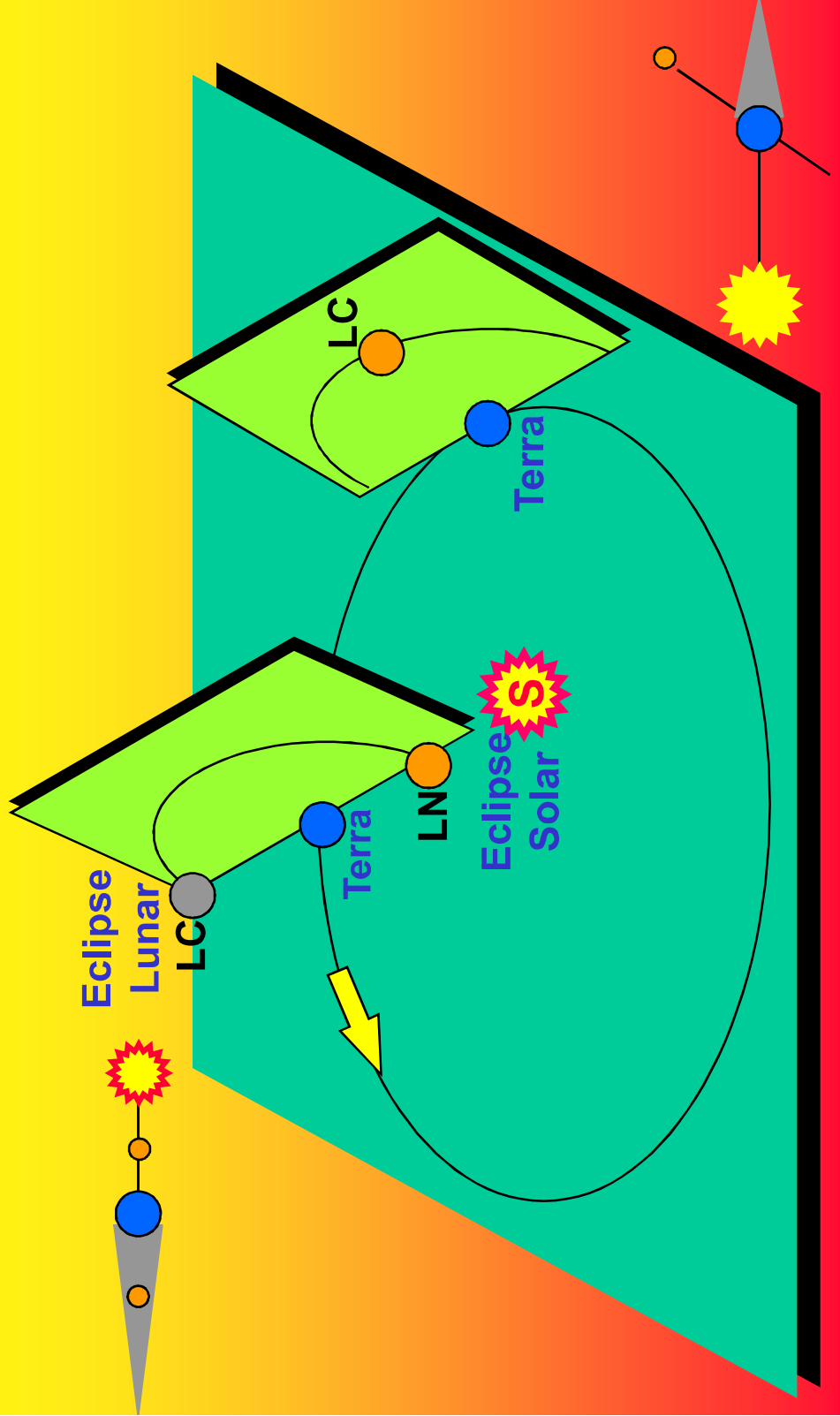


**Porque não ocorrem 2
ou 3 eclipses por mês?**

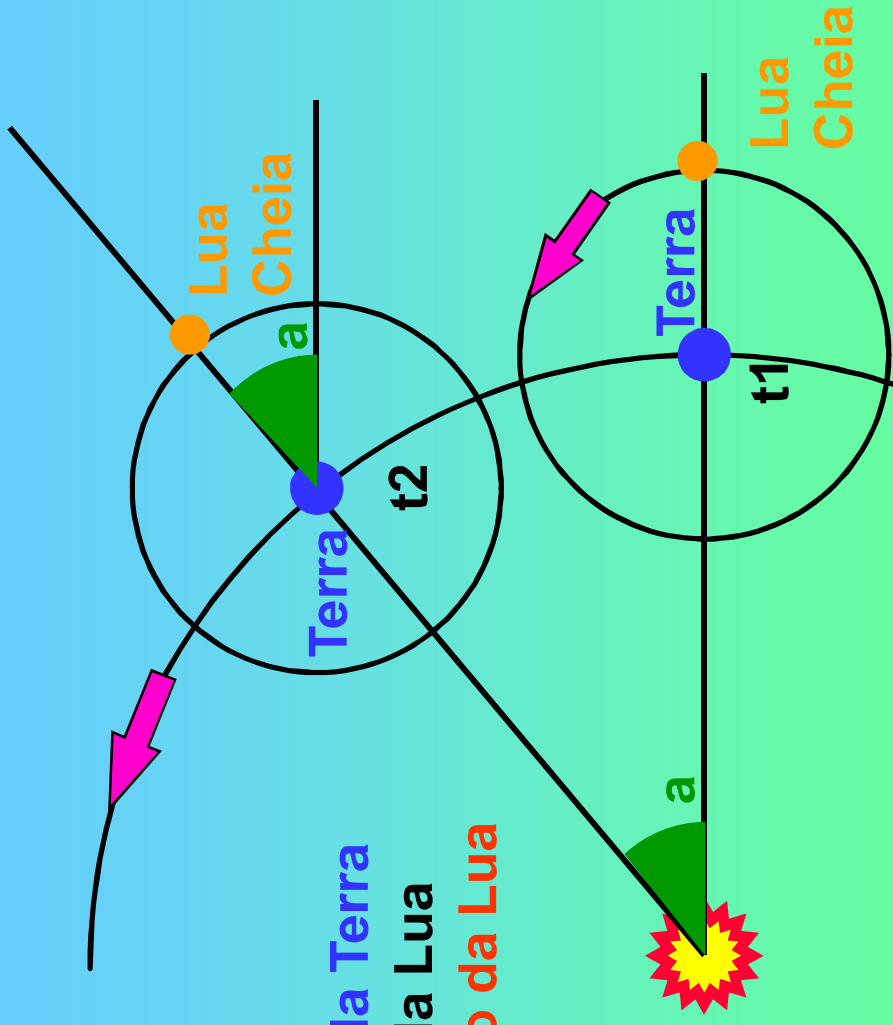


Lunação = 29,583582 dias

Eclipses e fases da Lua



Período orbital da Lua



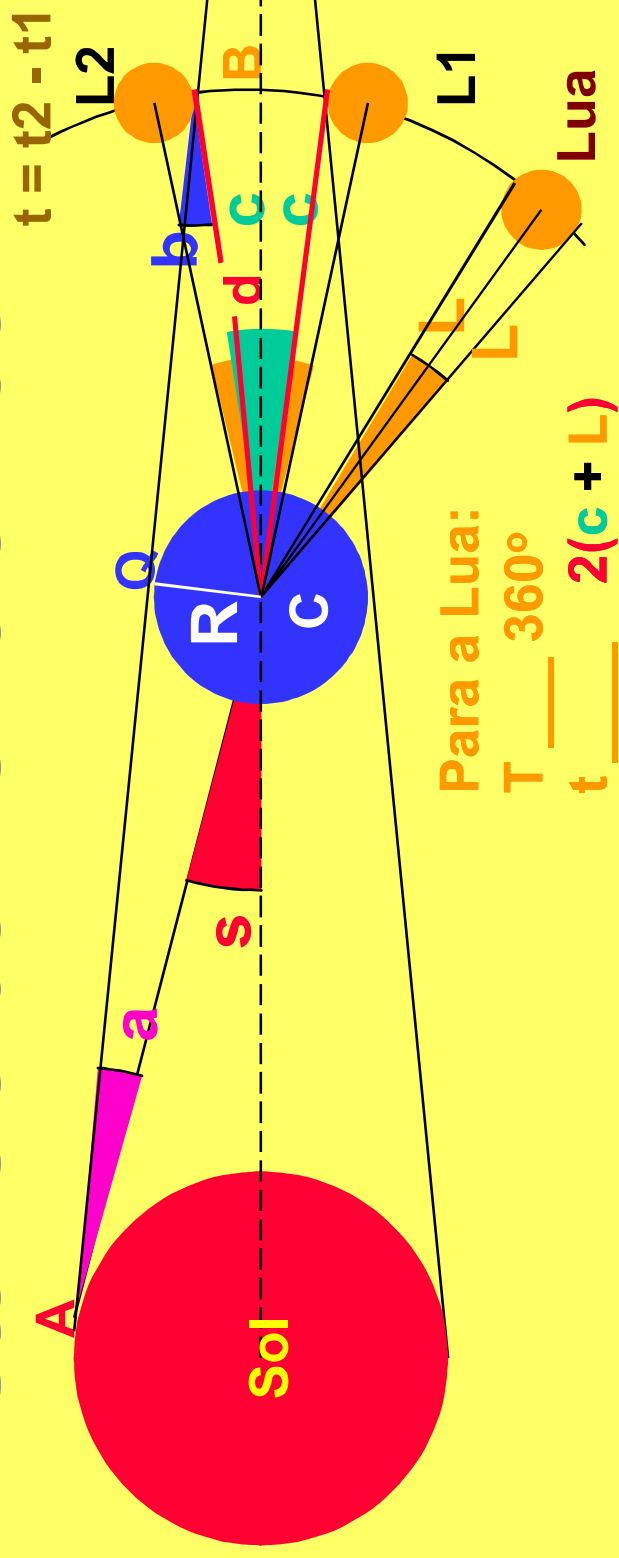
A = período orbital da Terra
T = período orbital da Lua
S = período sinódico da Lua

Terra:
A 360°
S a

Lua:
S 360 + a
T 360°

S = 29,530589 dias
T = 27,321660 dias

Distância da Terra à Lua



No triângulo ABC: $a + b + x = 180^\circ$

Ângulo raso em C: $s + x + c = 180^\circ$

$$a + b + x = s + x + c$$

$$a + b = s + c$$

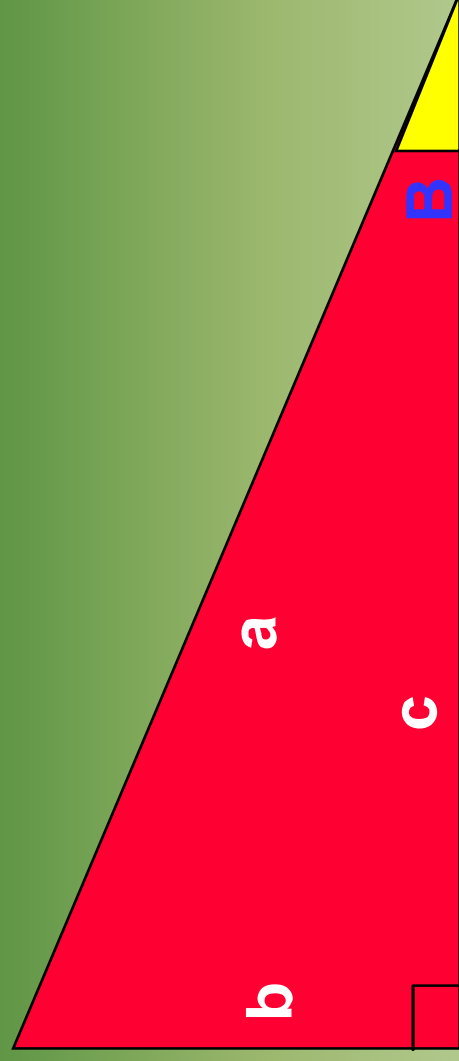
$$a \sim 0$$

No triângulo BCQ: $\text{sen } b = R / d$

Logo: $d = R / \text{sen } b$

$$b = s + c$$

Trigonometria no triângulo retângulo

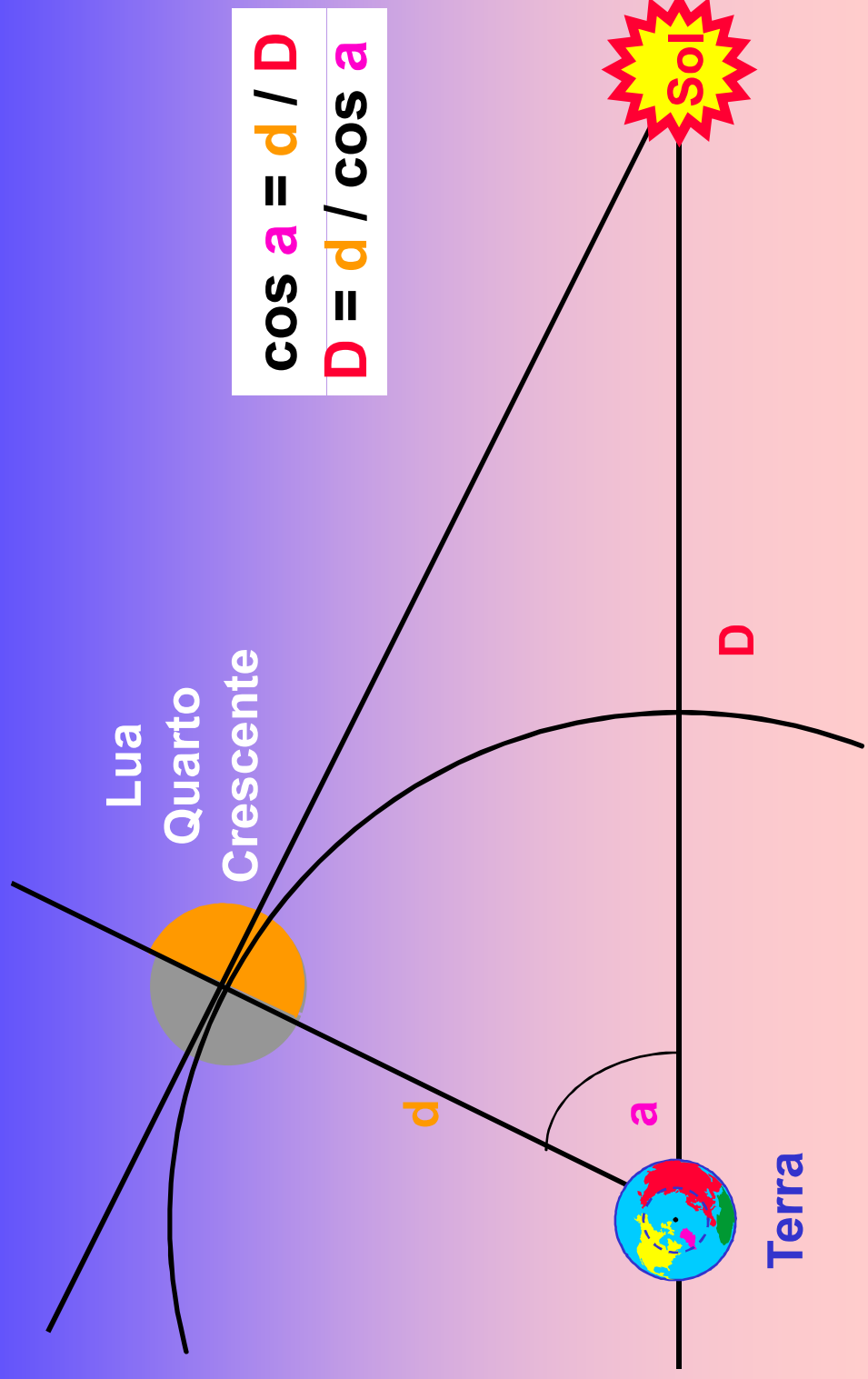


sen B = Cateto SEparado / Hipotenusa

cos B = Cateto COLado / Hipotenusa

Distância da Terra ao Sol

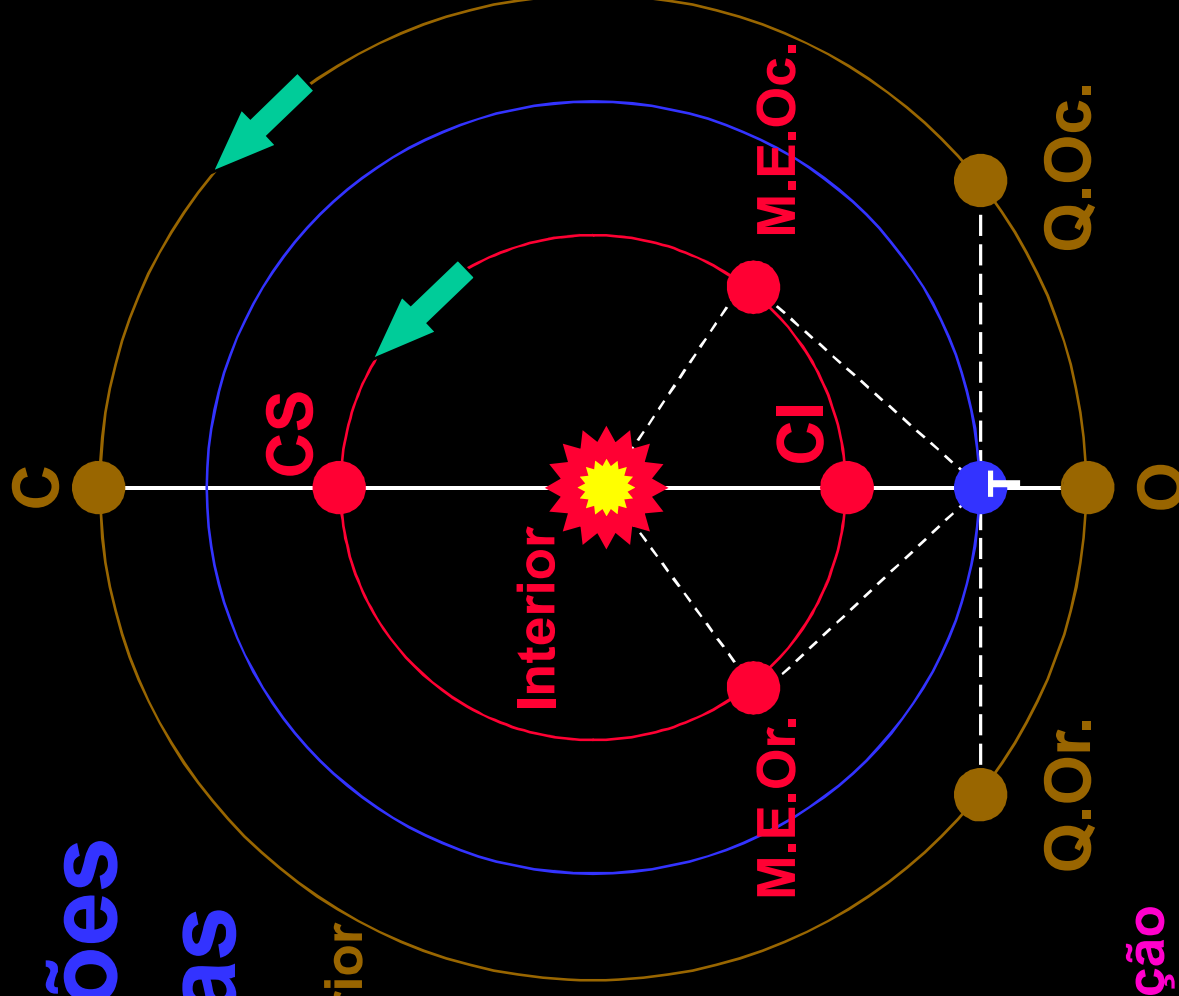
(Aristarco, séc. III a.C.)



$\cos a = d / D$
$D = d / \cos a$

Configurações Planetárias

Exterior



C = Conjunção

O = Oposição

Q = Quadratura

Oc. = Ocidental (W)

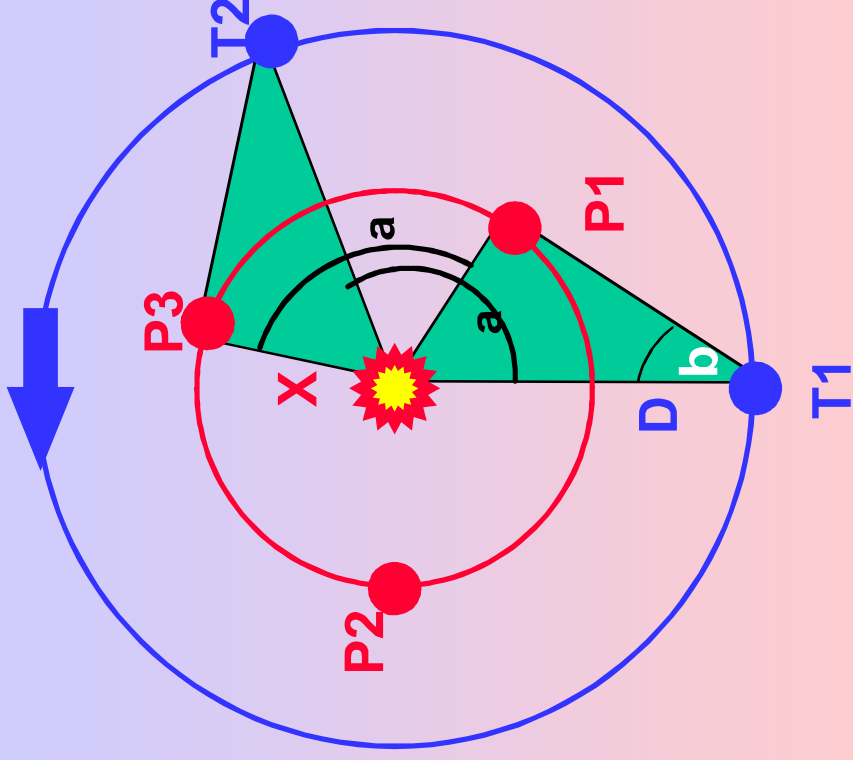
Or. = Oriental (E)

S = Superior

I = Inferior

ME = Máxima Elongação

Planetas Interiores



Distância X:
 $\text{sen } b = X / D$
 $X = D \cdot \text{sen } b$

Períodos

$$S = t_3 - t_1 = \text{Per. Sinódico}$$

$$T = ? = \text{Per. Orbital}$$

$$A = 365,256 \text{ (Orb. da Terra)}$$

Terra

$$A \text{ --- } 360^\circ$$

$$S \text{ --- } a$$

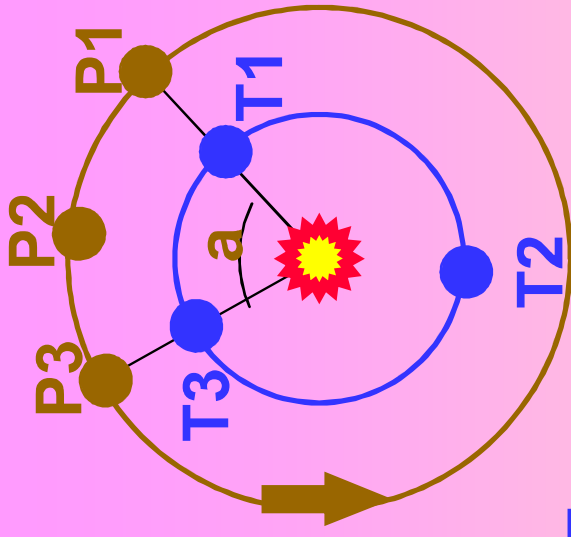
Planeta

$$S \text{ --- } 360 + a$$

$$T \text{ --- } 360^\circ$$

$$1/T = 1/A + 1/S$$

Planetas Exteriores



Terra

$$A \quad \underline{\quad} \quad 360^\circ$$

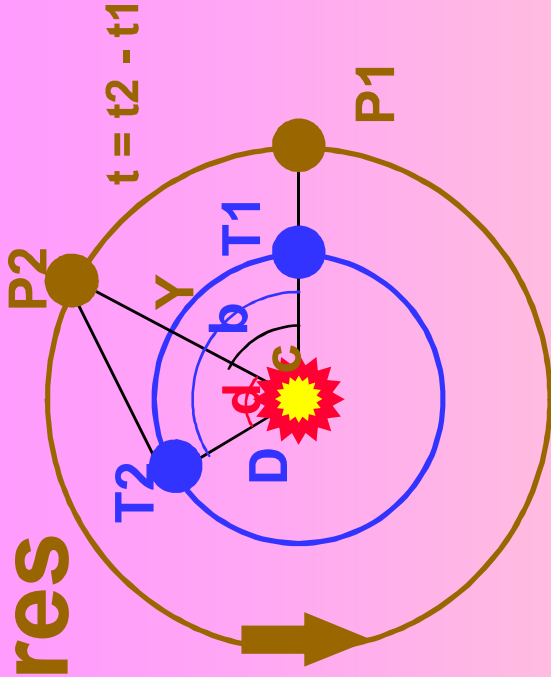
$$S \quad \underline{\quad} \quad 360 + a$$

Planeta

$$S \quad \underline{\quad} \quad a$$

$$T \quad \underline{\quad} \quad 360^\circ$$

$$1/T = 1/A - 1/S$$



Terra

$$A \quad \underline{\quad} \quad 360^\circ$$

$$t \quad \underline{\quad} \quad b$$

Planeta

$$T \quad \underline{\quad} \quad 360^\circ$$

$$t \quad \underline{\quad} \quad c$$

$$d = b - c$$

$$\cos d = D / Y$$

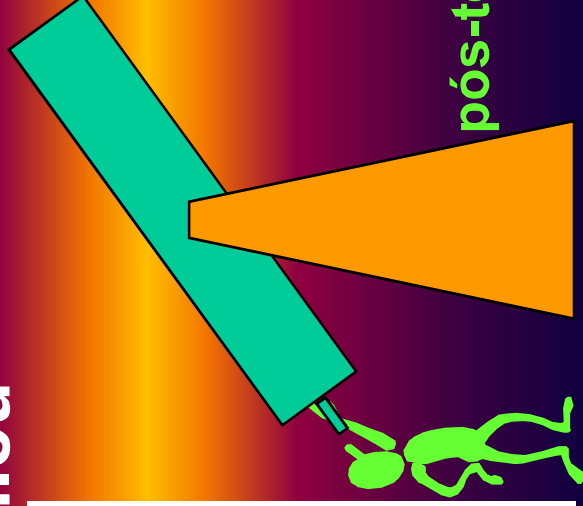
$$Y = D / \cos d$$

**Fim das
observações
a olho nu !**

Observações a olho nu e com telescópios



Galileu



Era pós-telescópio



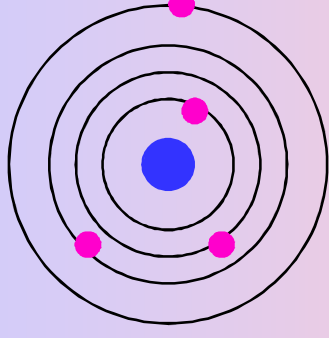
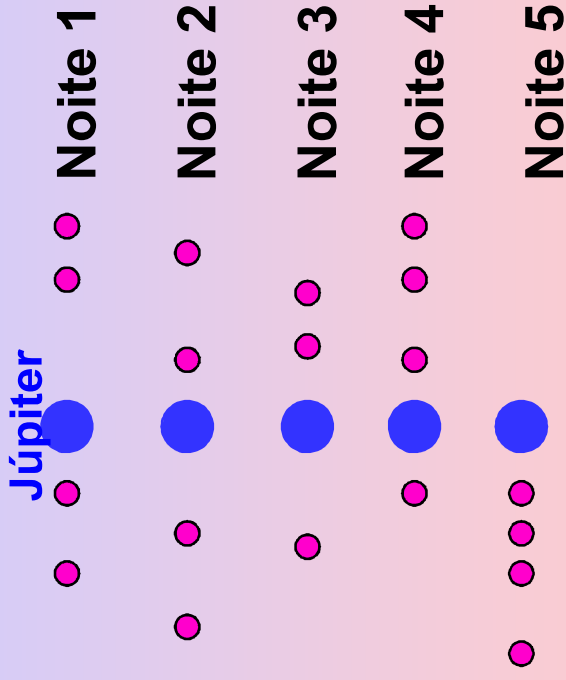
Era pré-telescópio

1609



Satélites de Júpiter

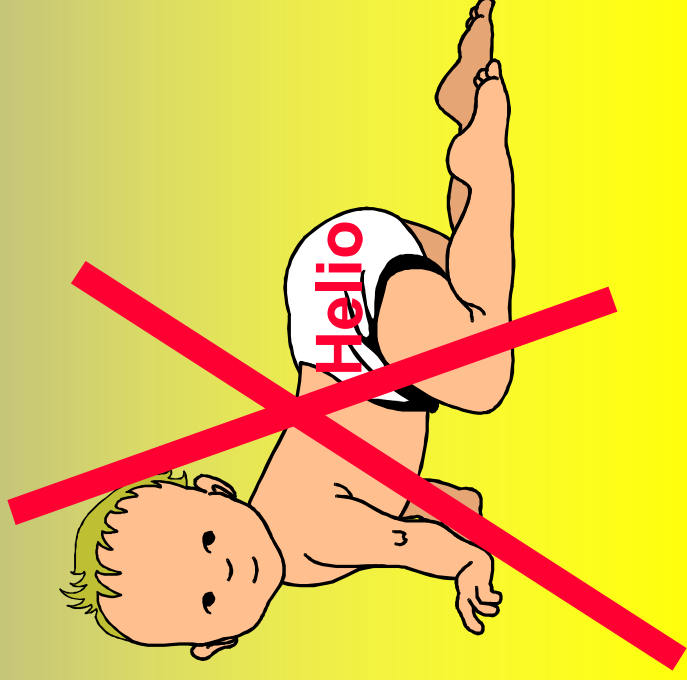
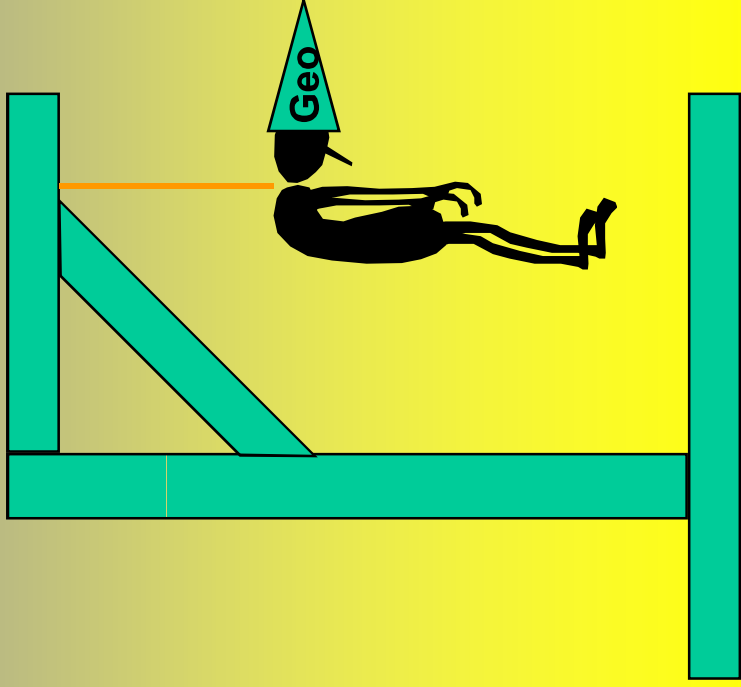
(Galileu, séc. XVII)



Os satélites
giram em torno
de Júpiter, e não
da Terra!

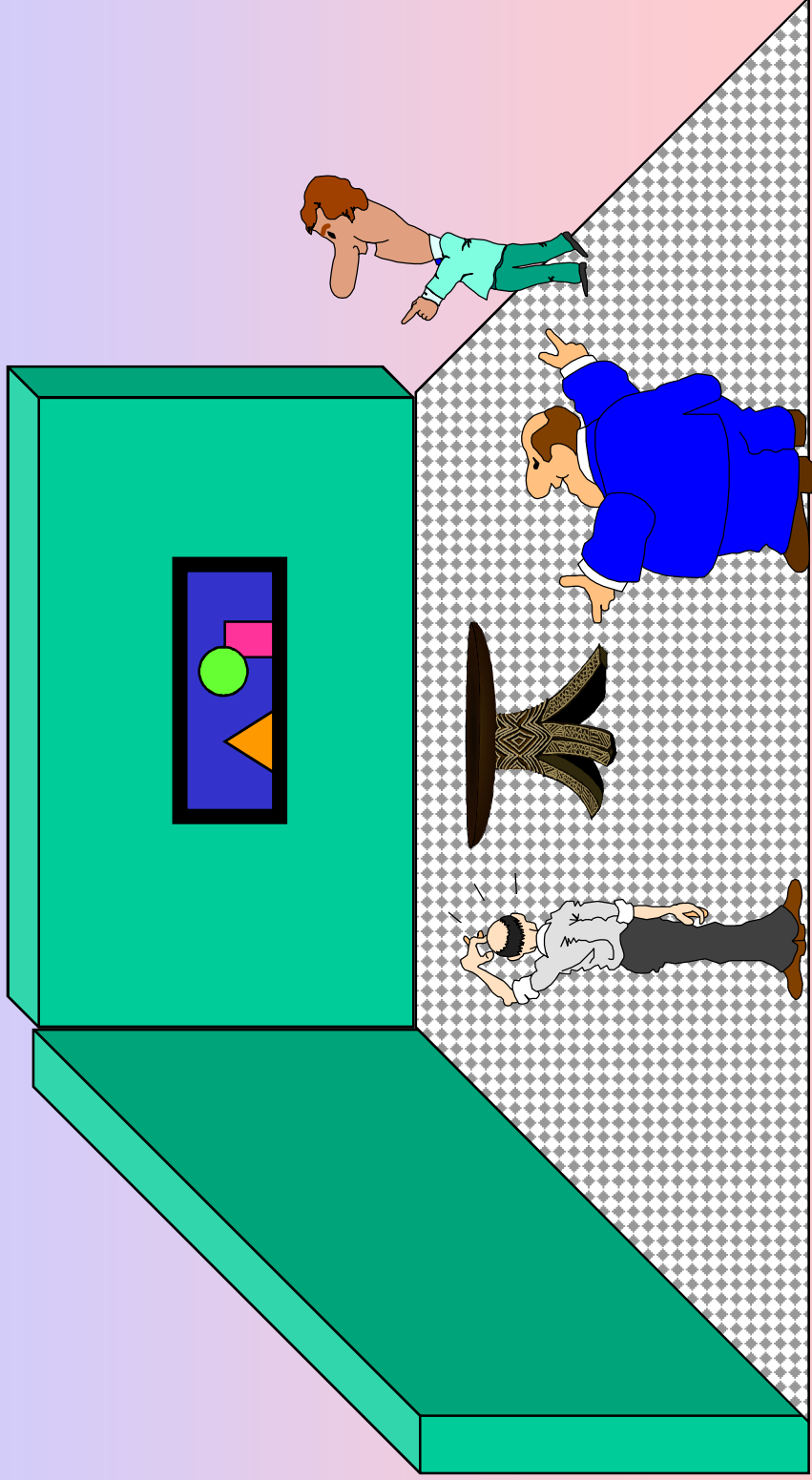


Morte do Sistema Geocêntrico!

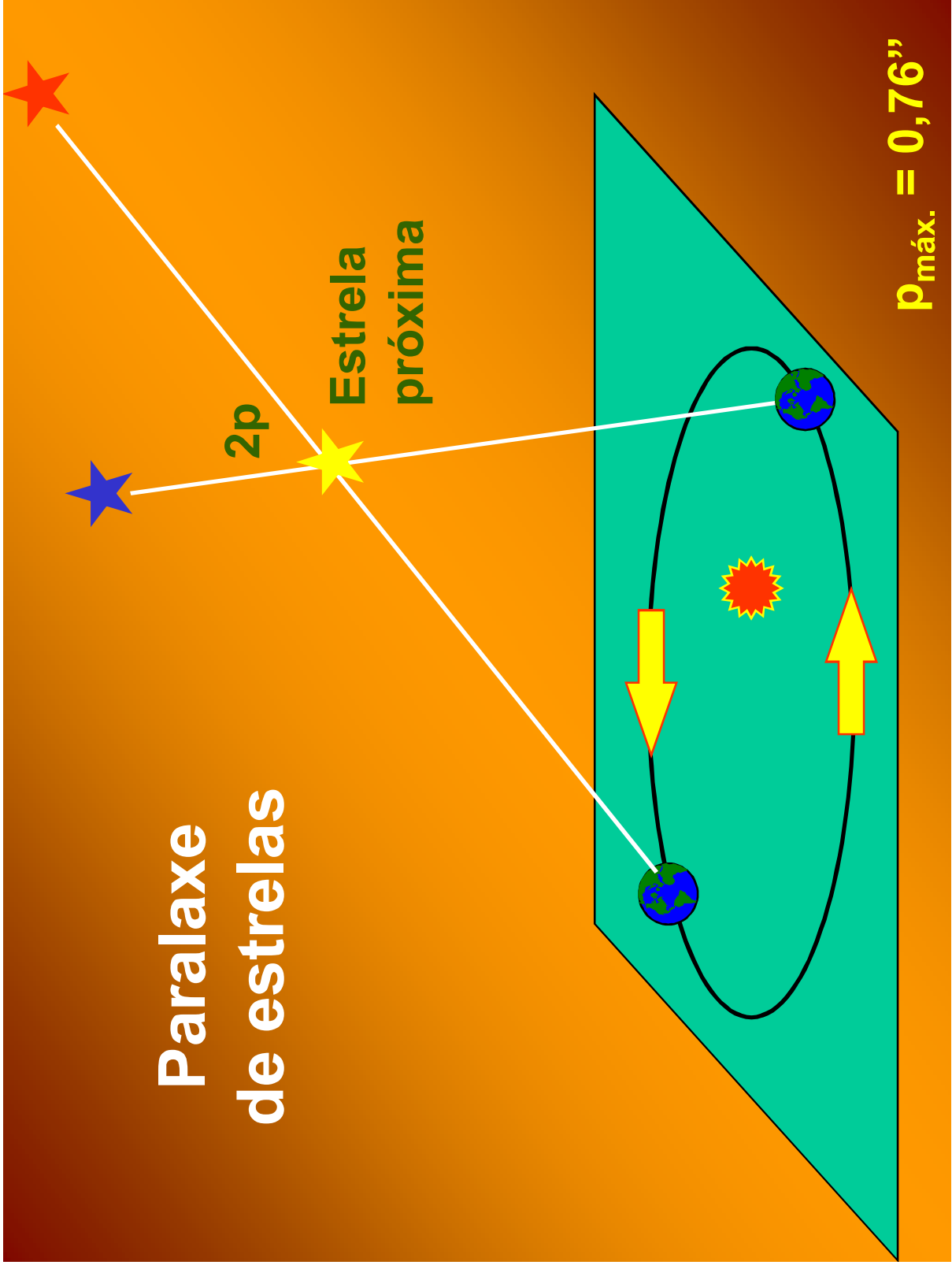


Prova da translação da Terra

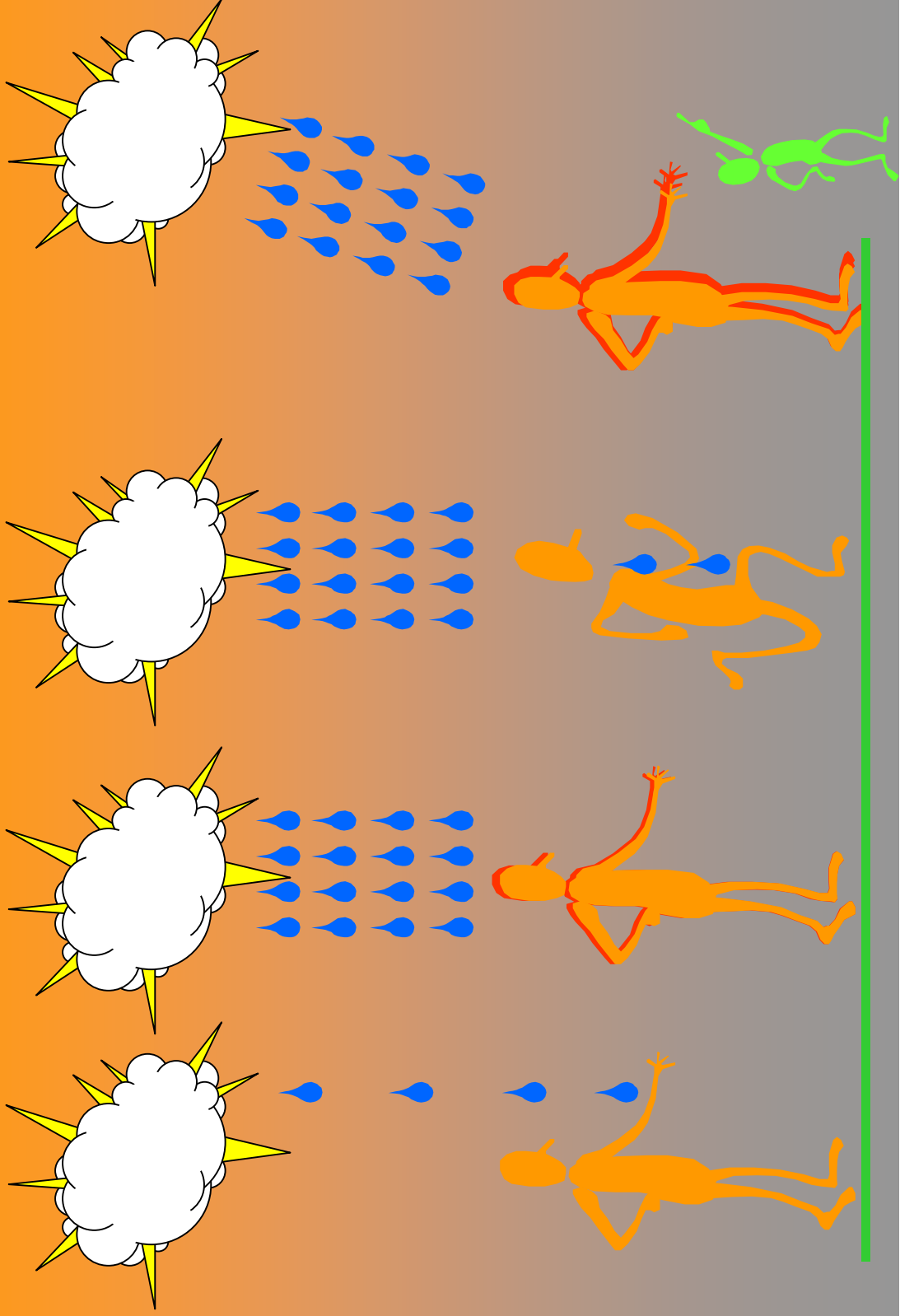
Efeito de Paralaxe



Paralaxe de estrelas



Correndo da chuva !



**Direção
real da
chuva**



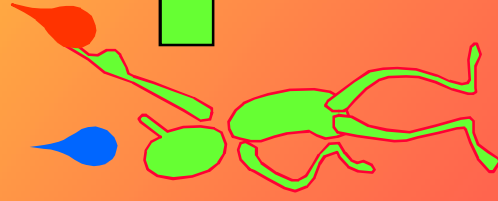
**Direção
aparente
da chuva**



**Direção
aparente
da chuva**



Composição de velocidades

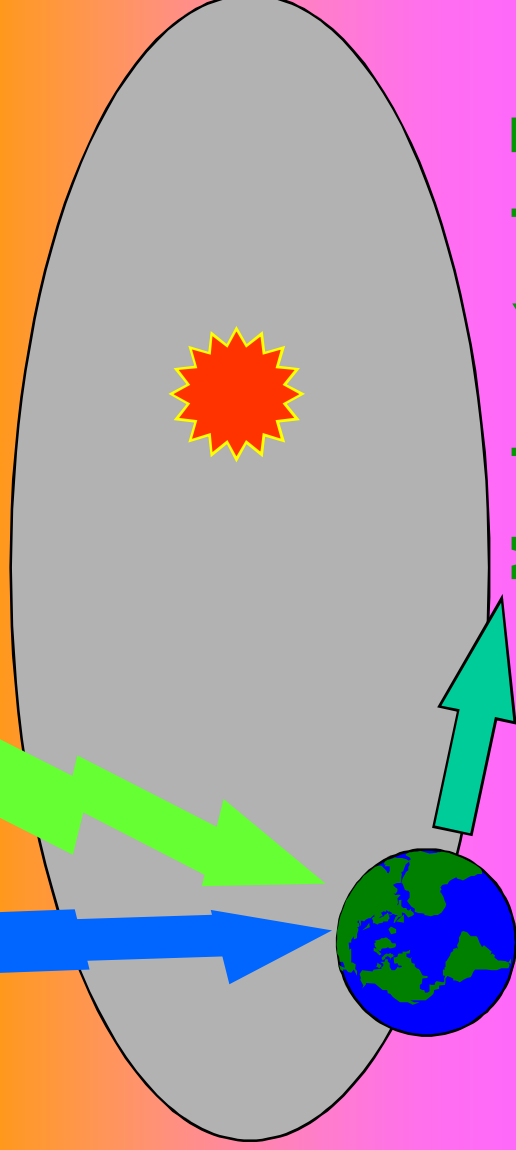


**Direção do
movimento
do observador**

★
Posição
real da
estrela

★
Posição
“observada”
da estrela

Aberração anual
(Bradley 1728)



Movimento da Terra

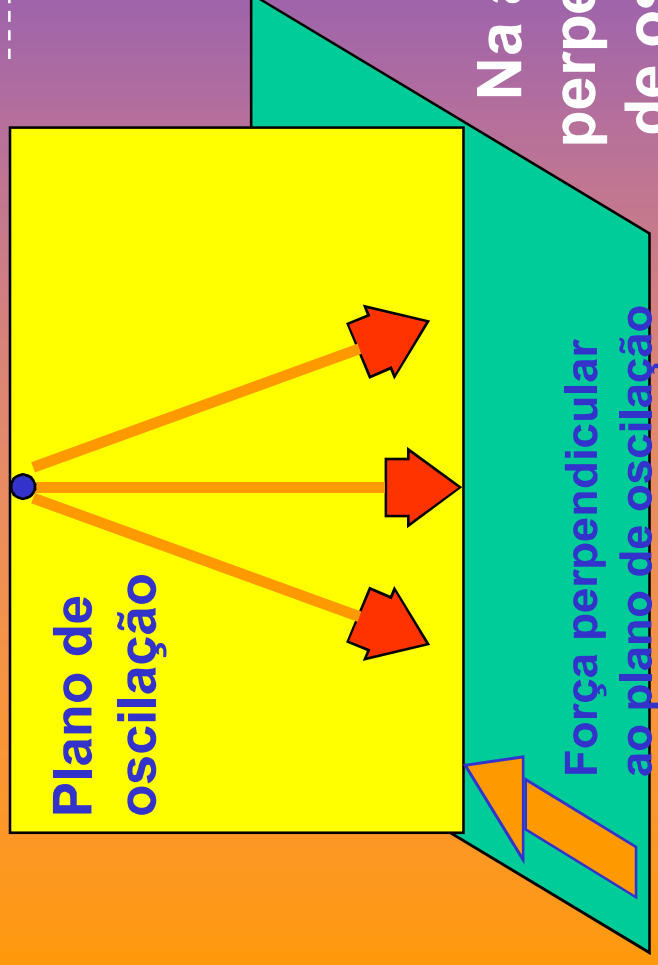
Rotação da Terra

Prova (?) da rotação da Terra



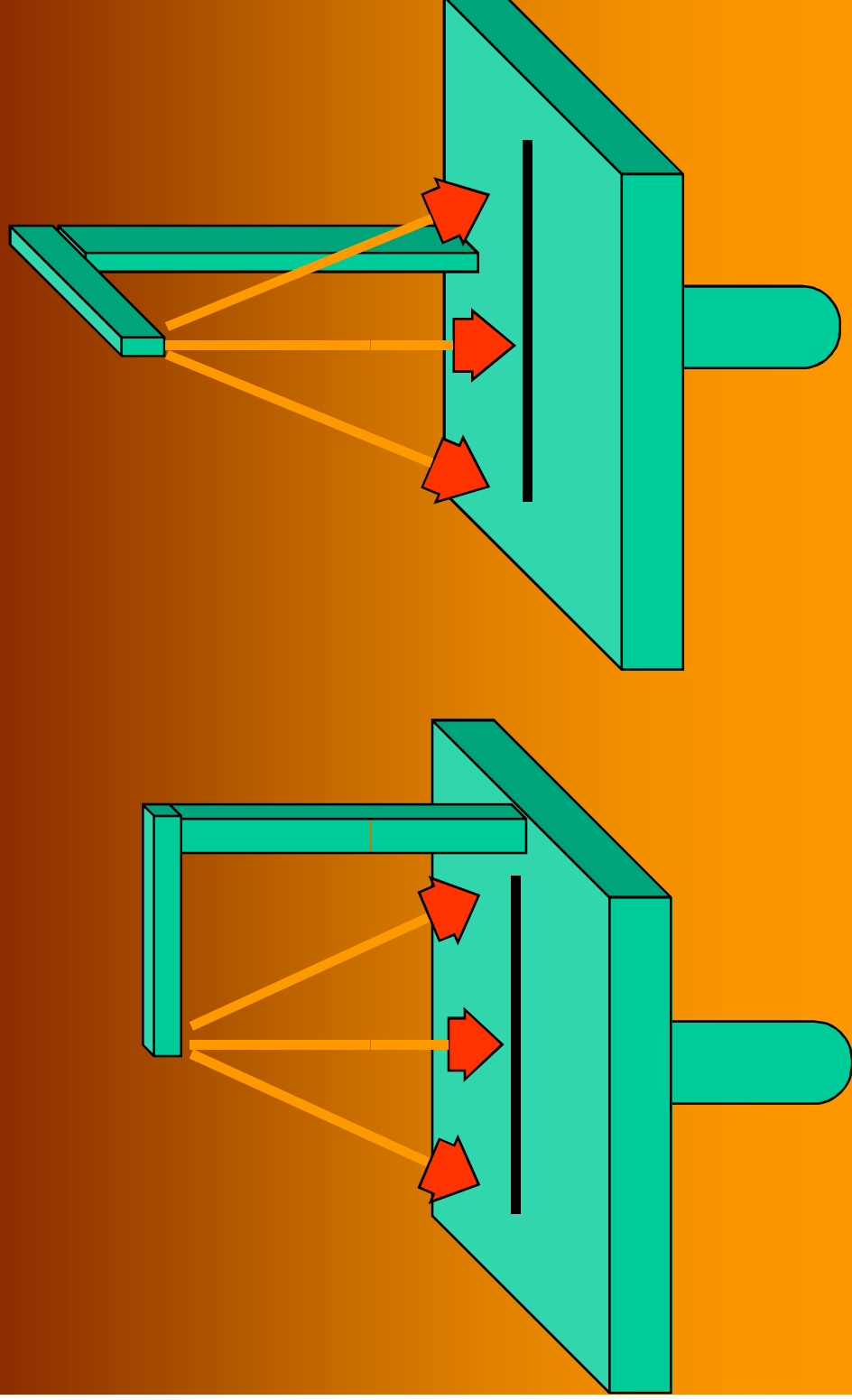
Galileu Galilei
(séc. XVII)

Invariabilidade do plano de oscilação

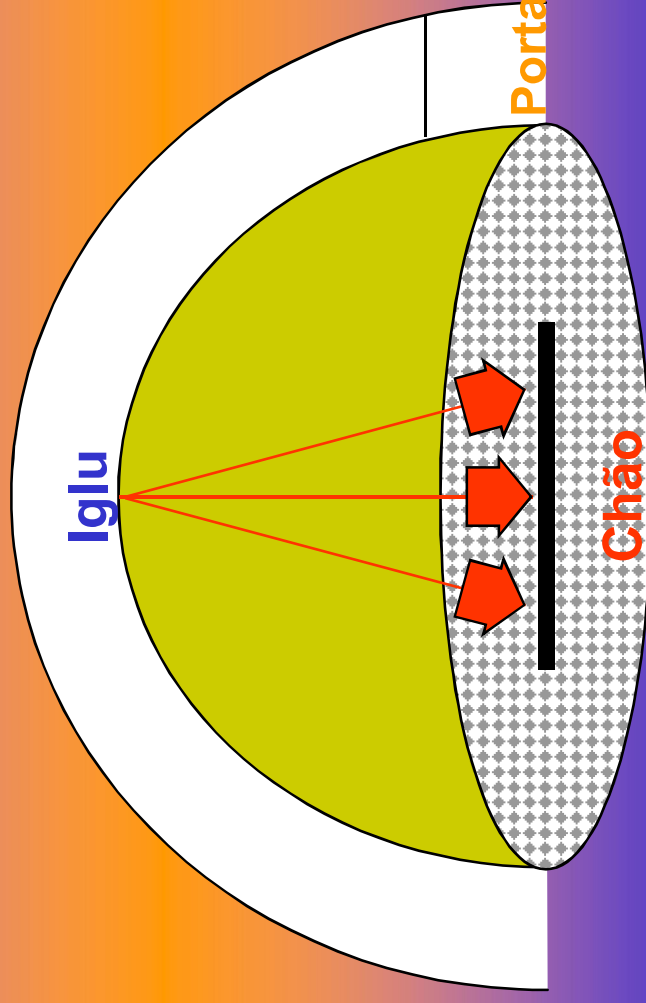
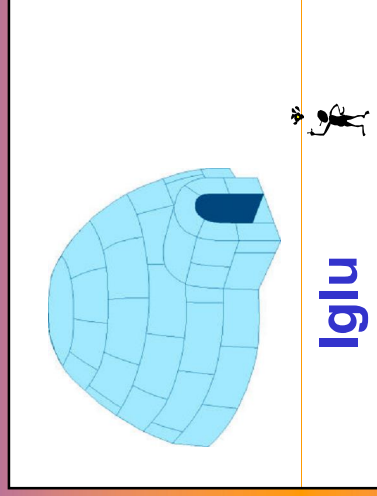


Na ausência de forças perpendiculares ao plano de oscilação, esse plano se mantém com direção fixa no espaço.

Pêndulo numa mesa giratória

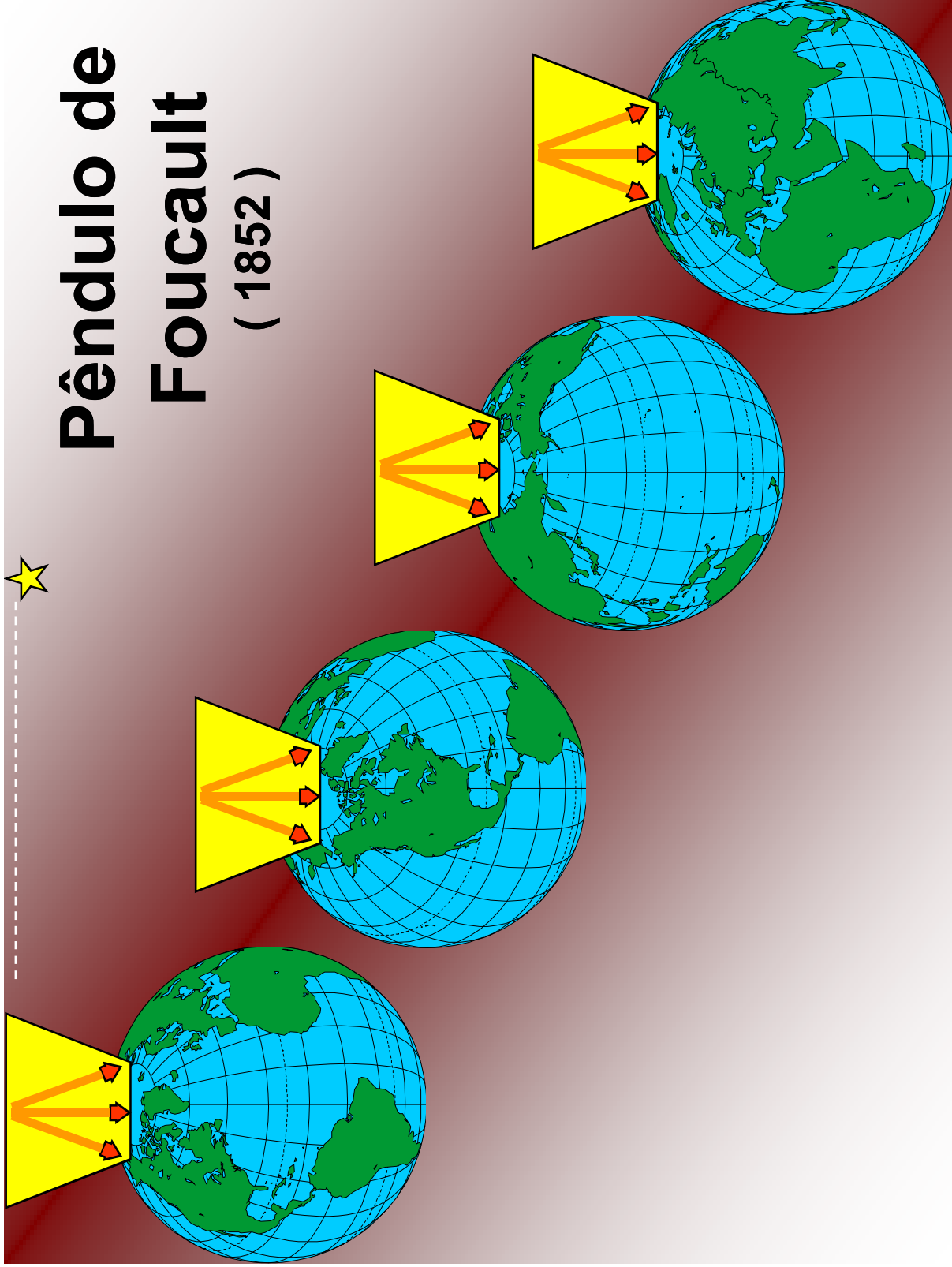


Pêndulo num iglu

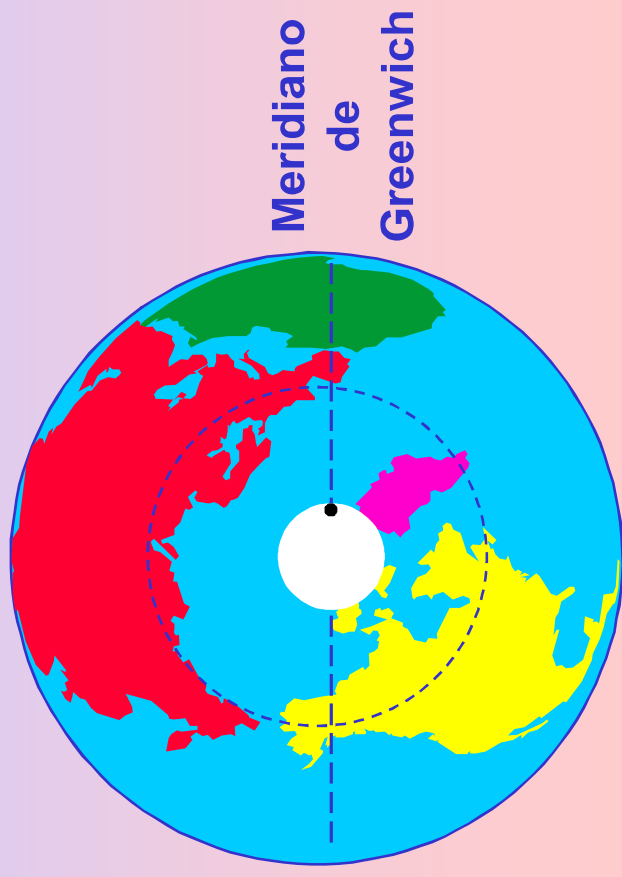
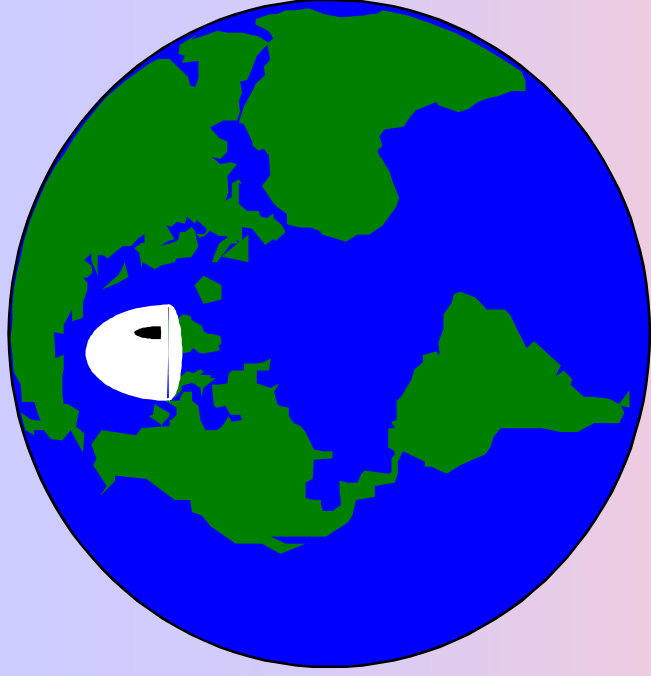


Corte vertical de um iglu

Pêndulo de Foucault (1852)



Experiência de Foucault

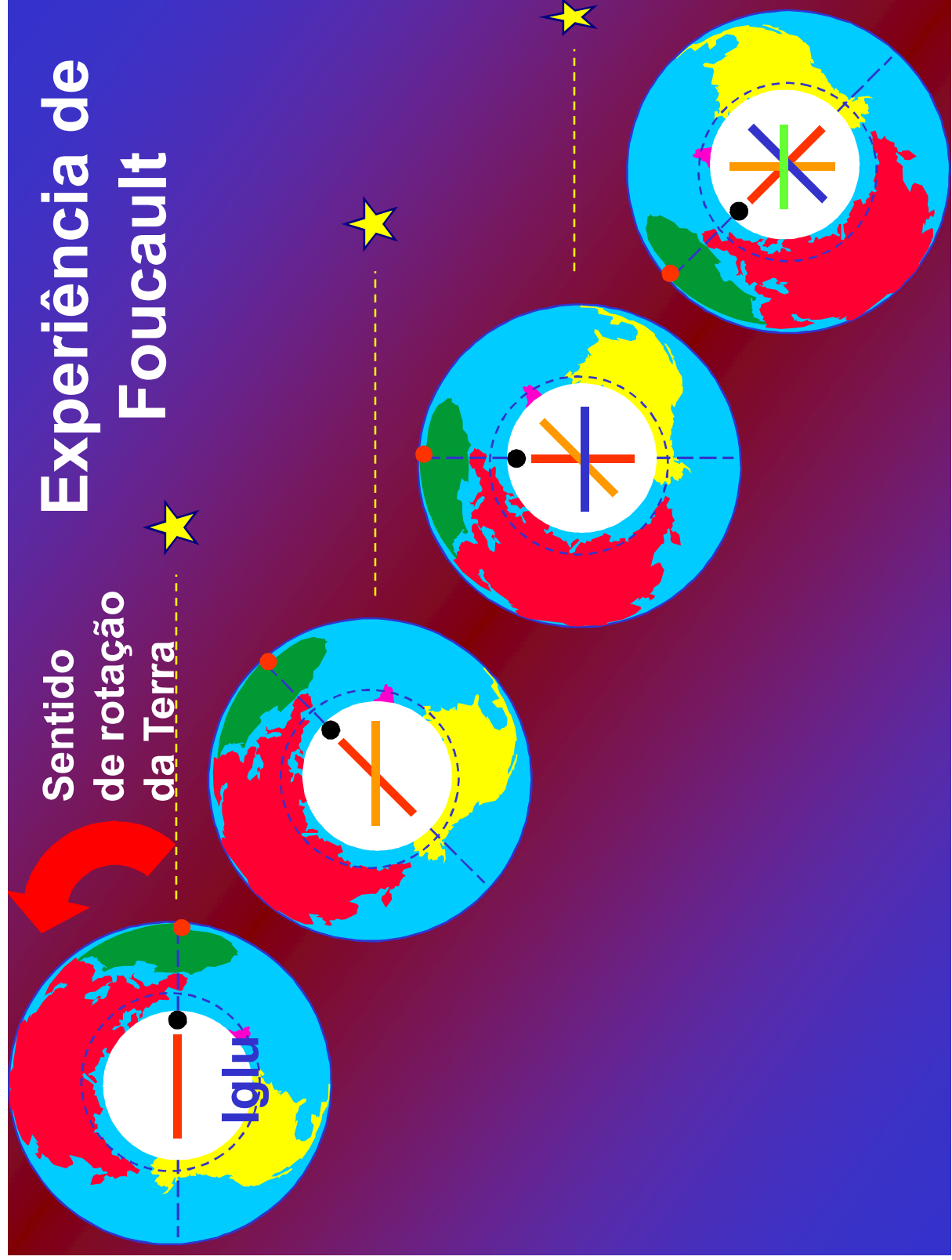


Meridiano
de
Greenwich

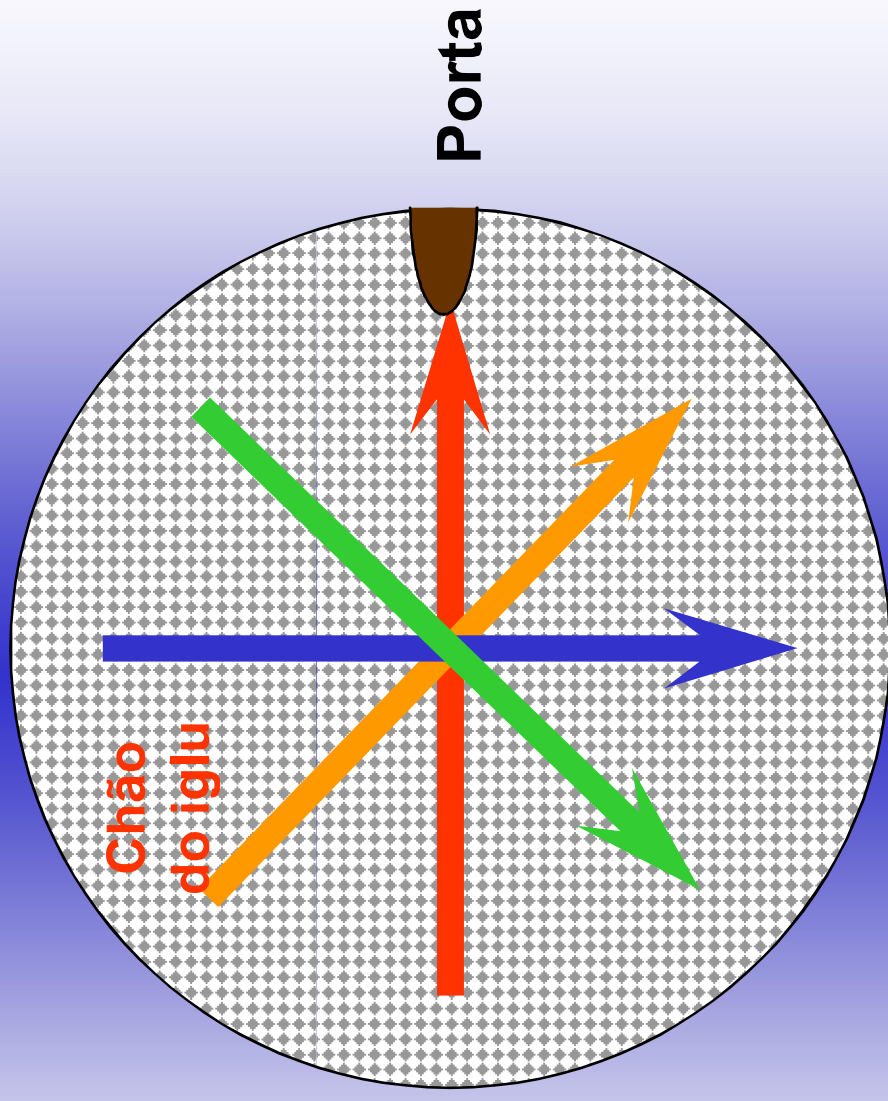
Terra vista desde o Pólo Norte

Experiência de Foucault

Sentido de rotação da Terra

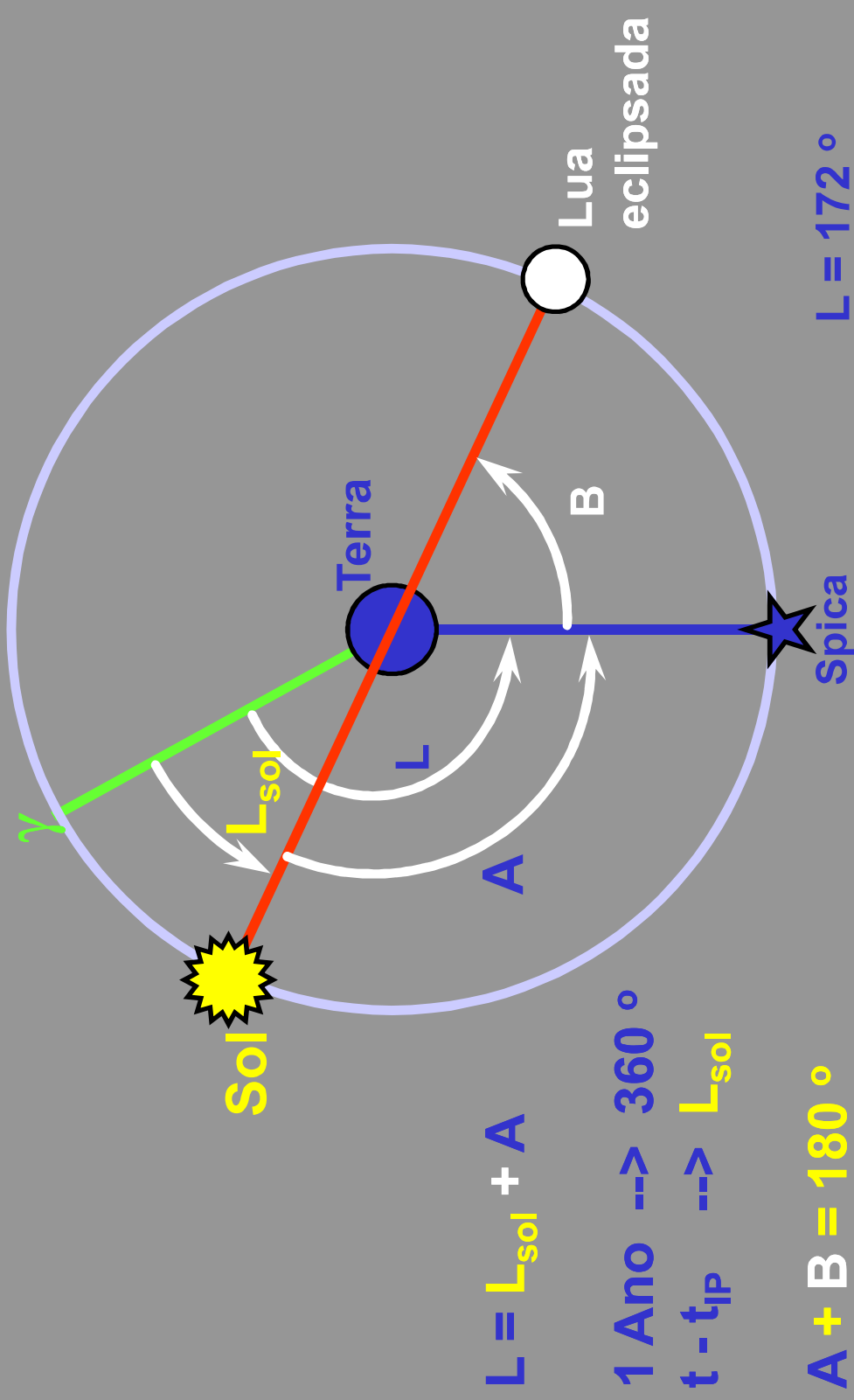


Experiência de Foucault vista de dentro do iglu

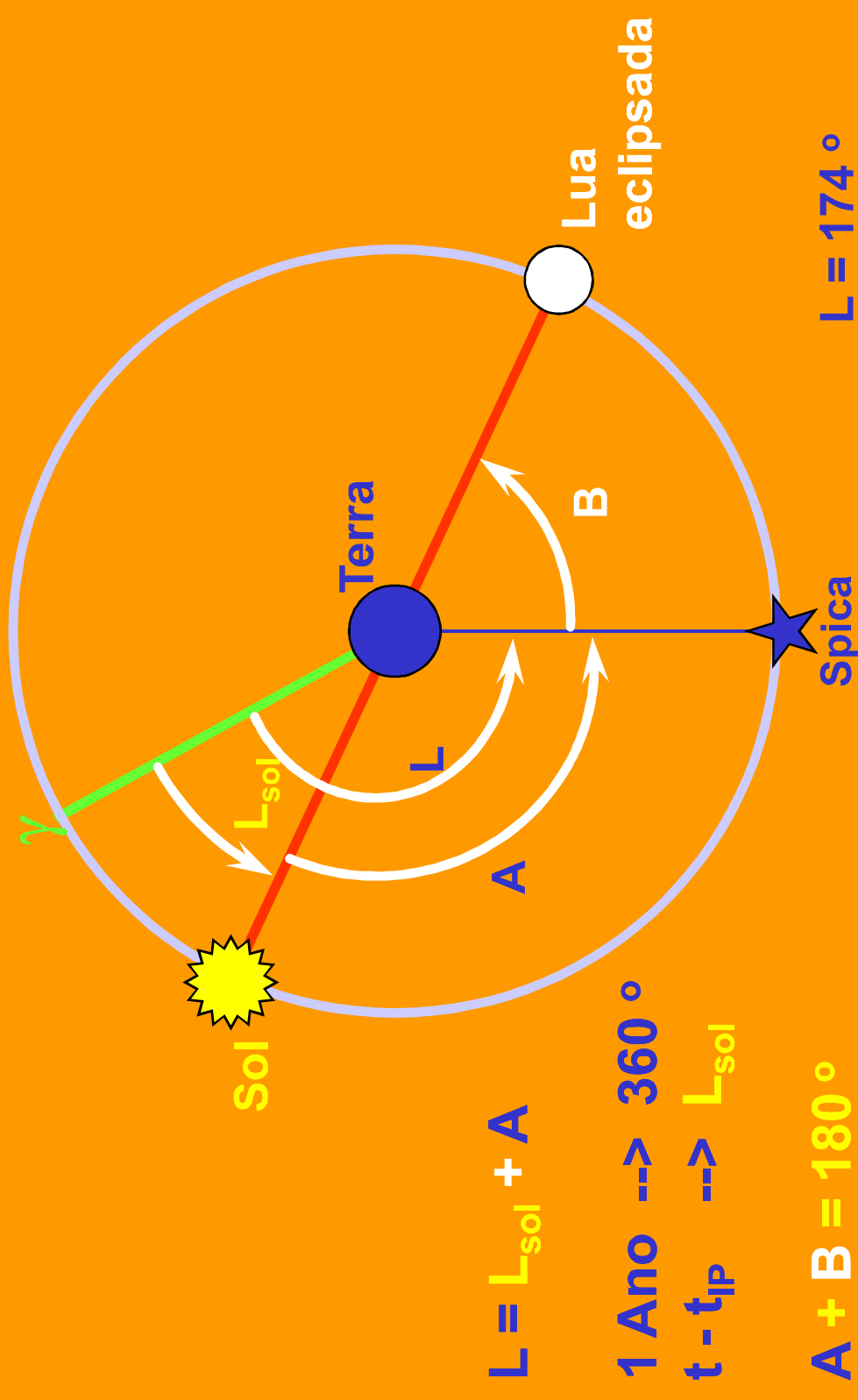


Precessão

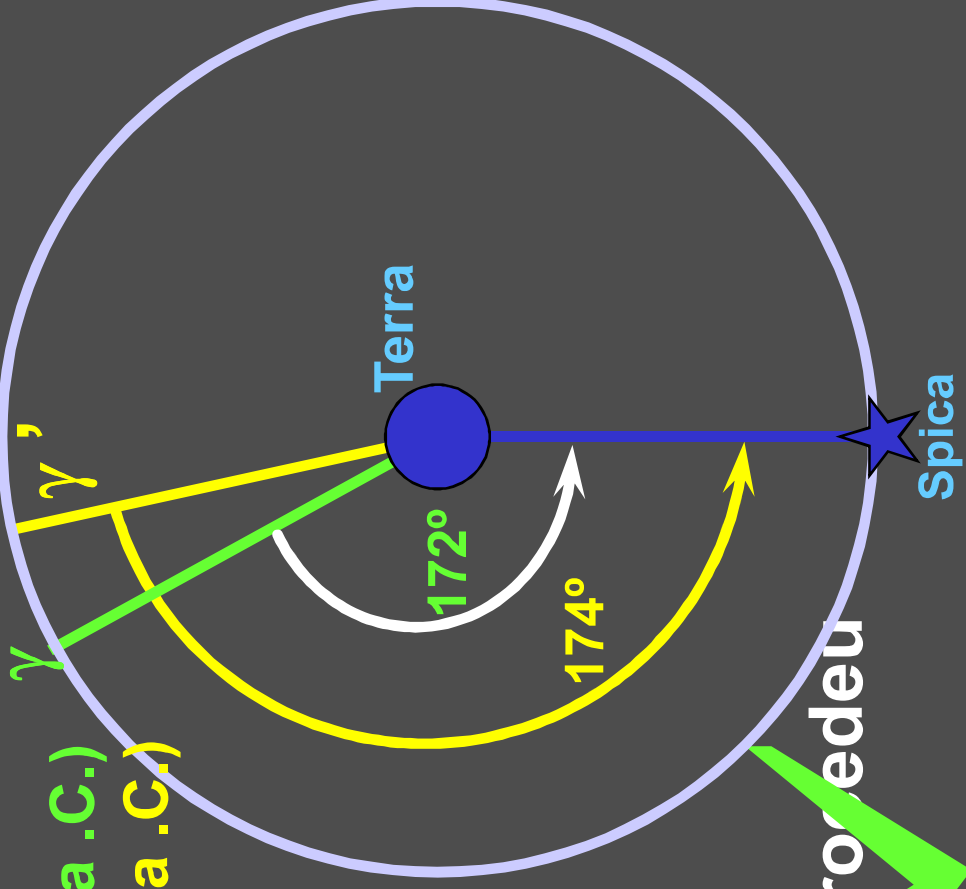
Longitude eclíptica de Spica segundo Timocharis (273 a .C.)



Longitude eclíptica de Spica segundo Hiparcos (129 a .C.)



Retrogradação do Equinócio segundo Hiparcos (129 a .C.)



Timocharis: 172° (273 a .C.)

Hiparcos : 174° (129 a .C.)

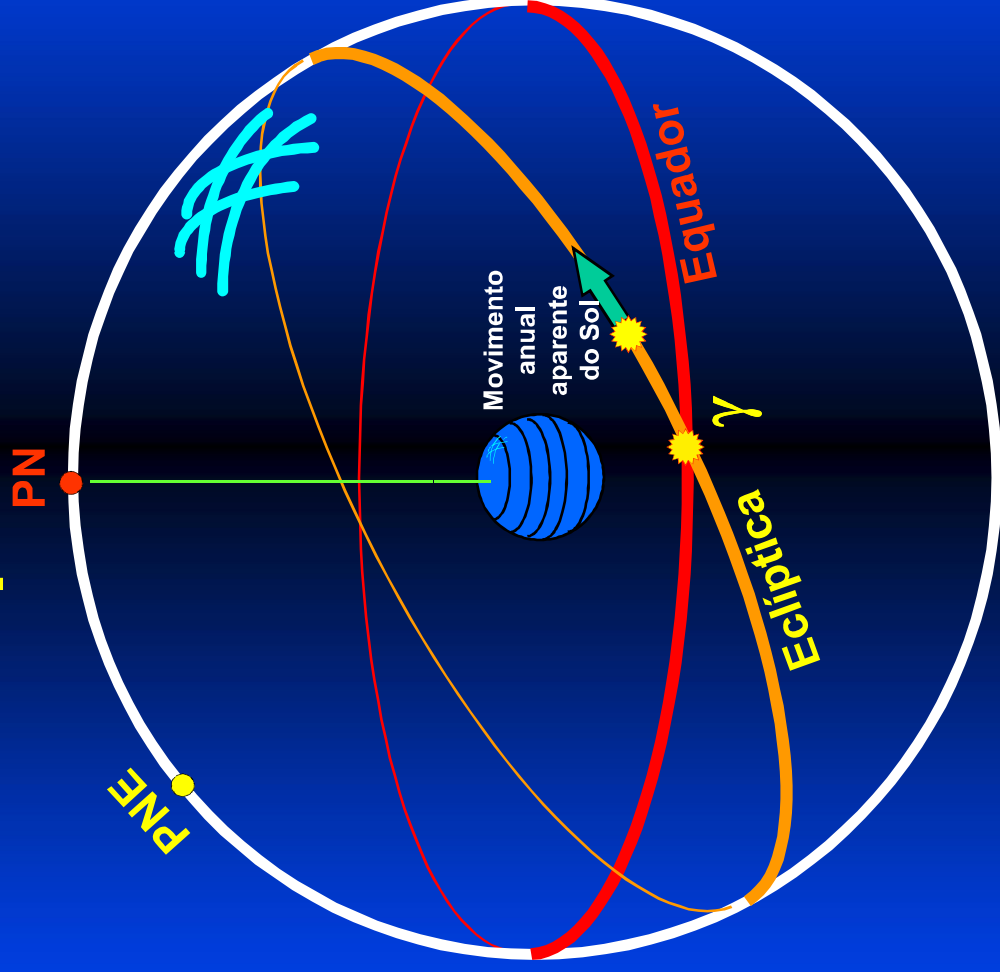
Hipóteses

~~Timocharis errou.~~

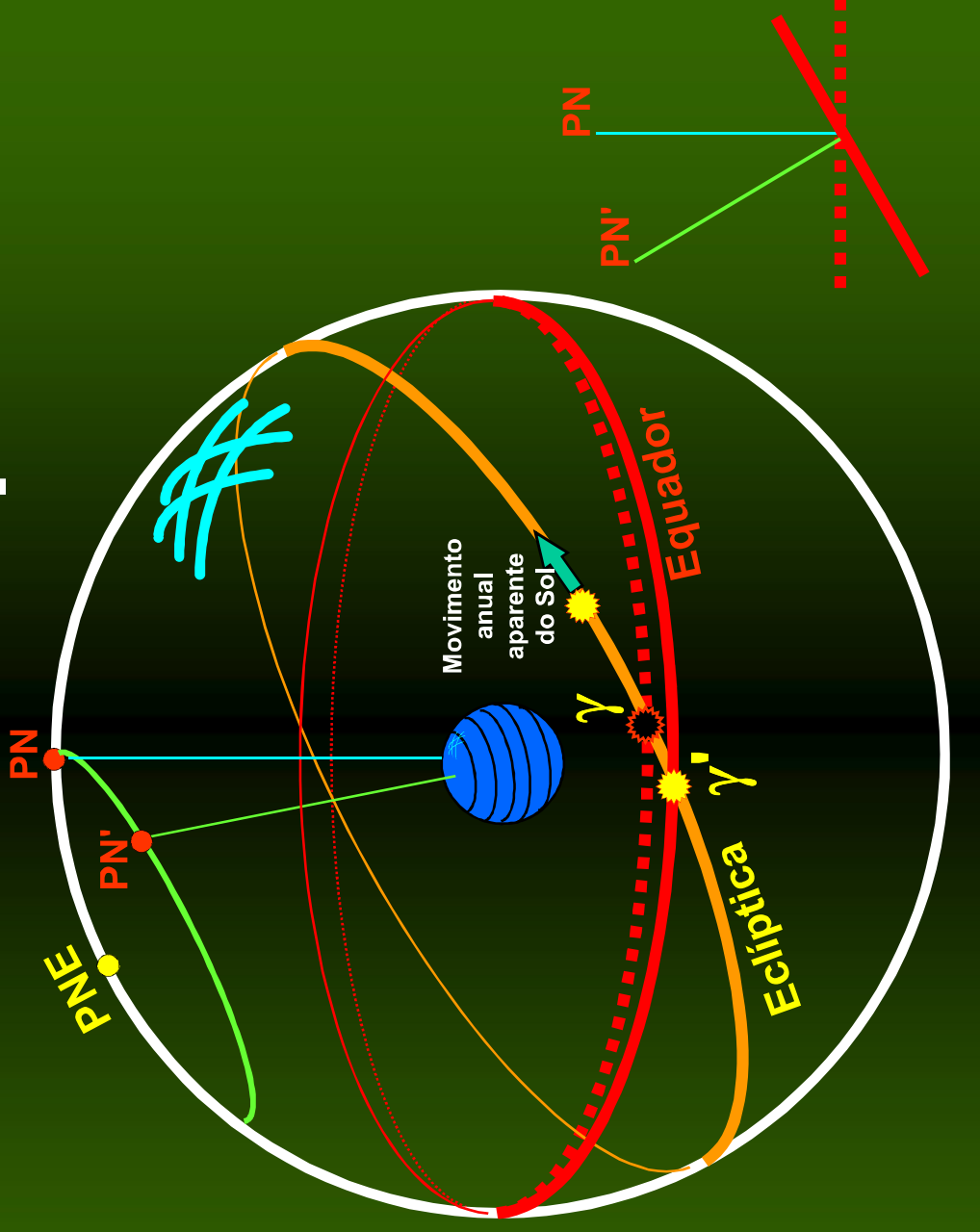
~~Spica se deslocou
de 2° em 144 anos.~~

O ponto Vernal retrocedeu
2° em 144 anos. ✓

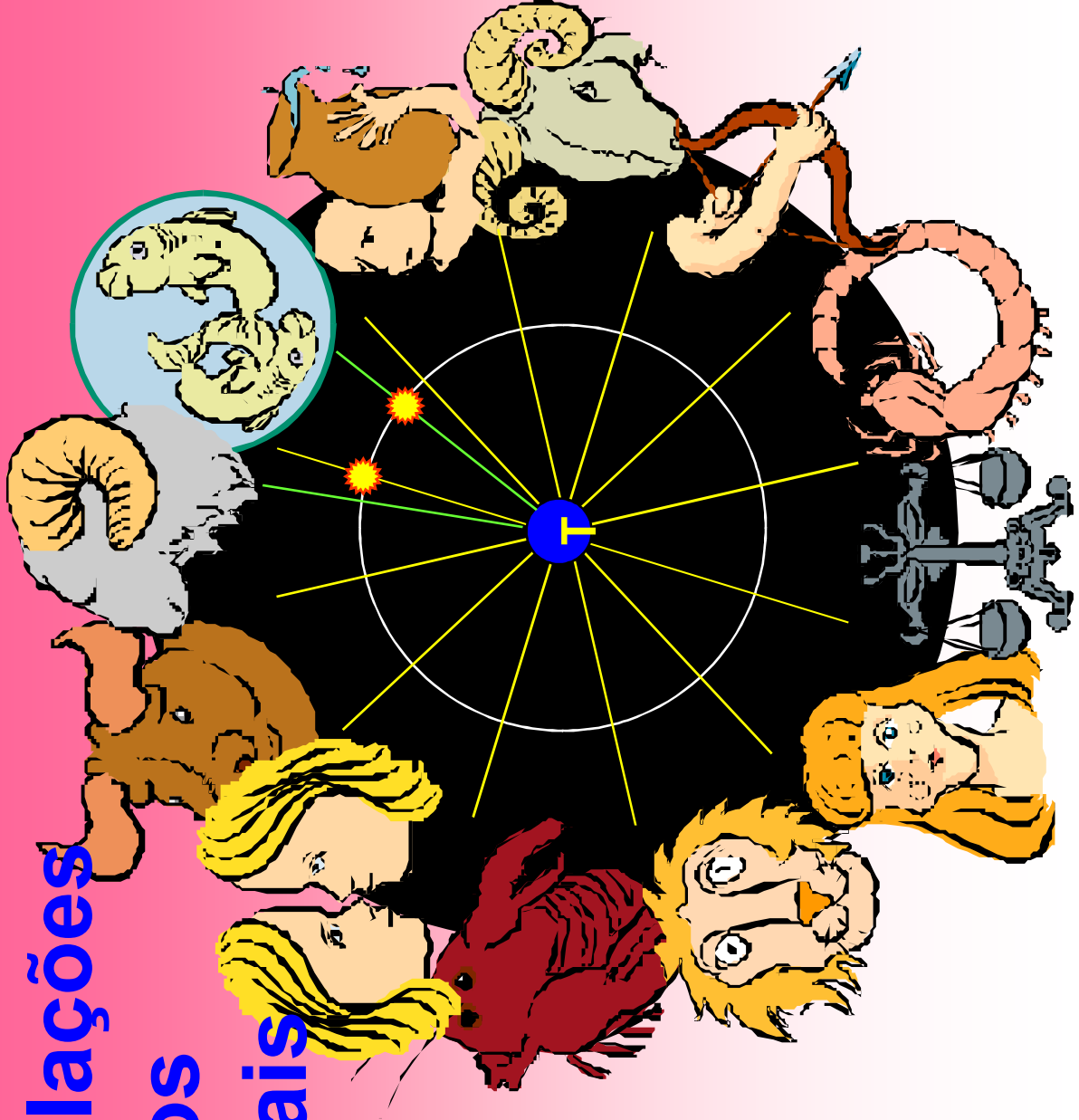
Equinócio da primavera boreal (γ)



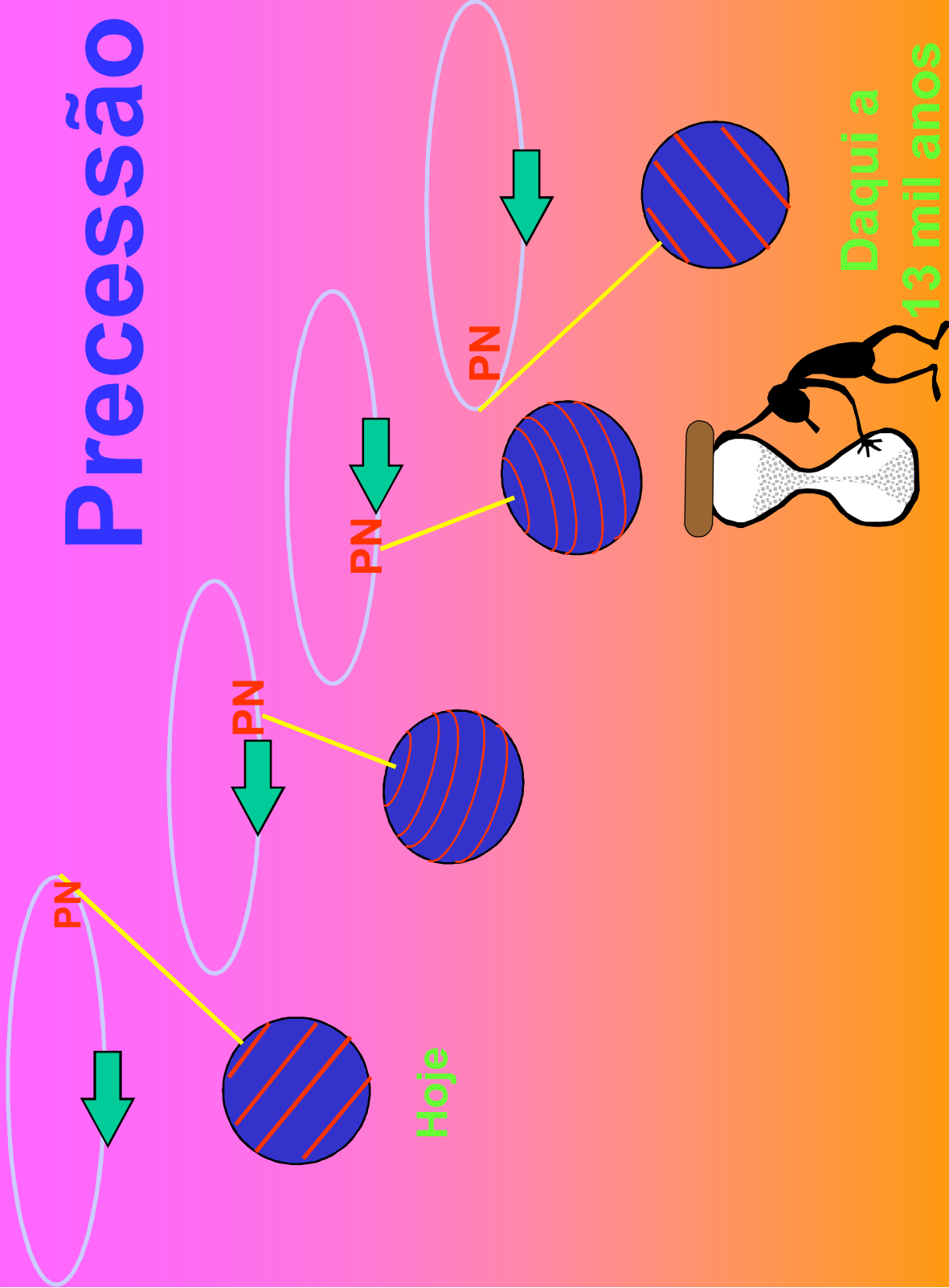
Precessão dos equinócios



Constelações e Signos Zodiacais

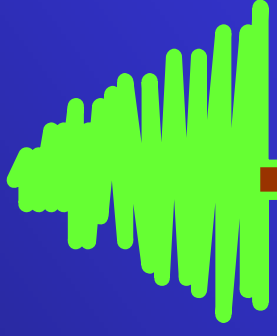


Precessão



**E como se determina
a distância até uma
estrela?**

Distância até o outro lado do rio



A

$$A = 180 - B - C$$

$b = ?$

B

C

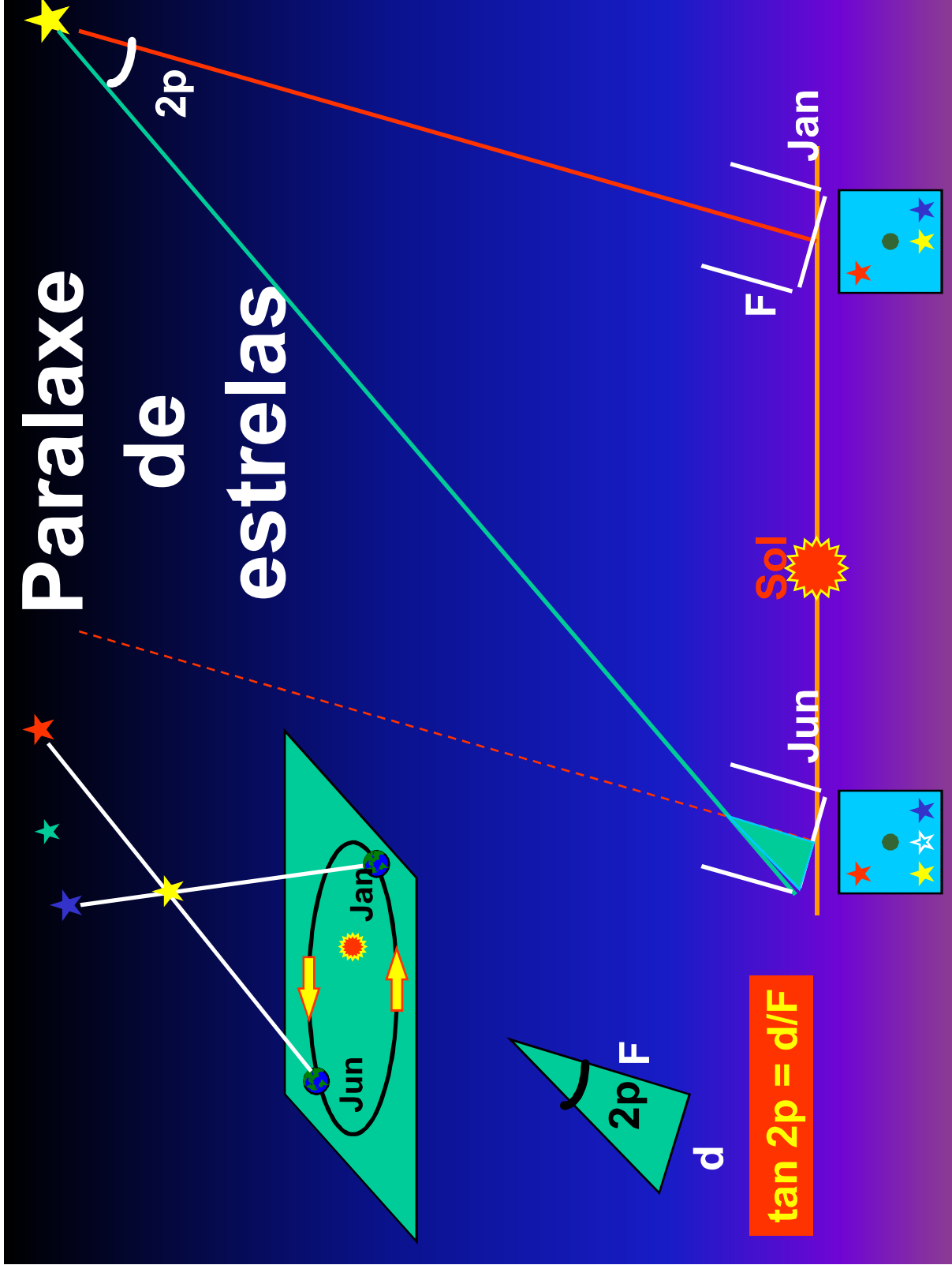
a

C



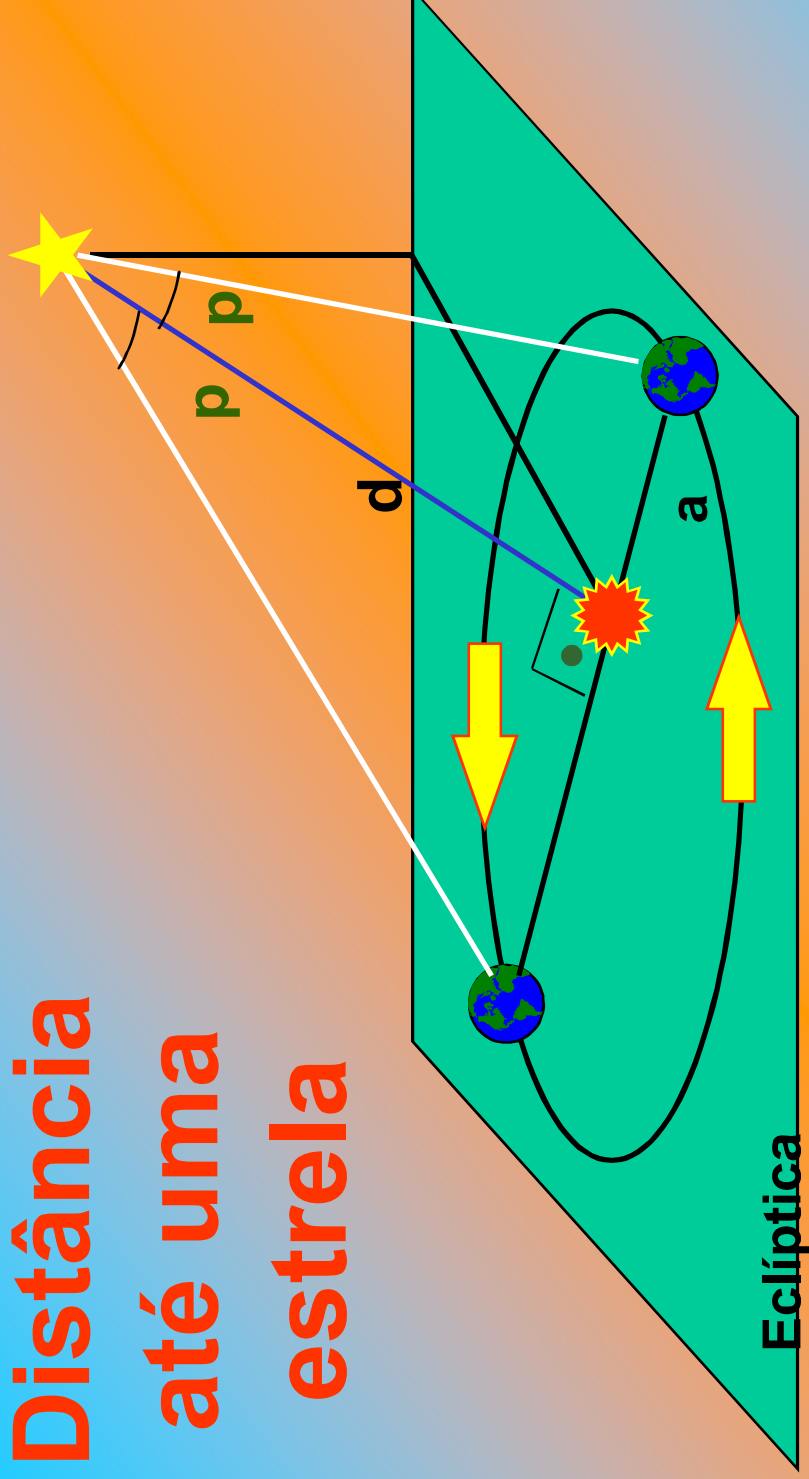
$$b / \sin(B) = a / \sin(A)$$

Paralaxe de estrelas



$\tan 2p = d/F$

Distância até uma estrela



$$\tan p = a / d$$



Firm