

Winnetu
41° N, 70° W

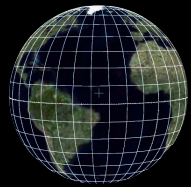
Lost without Longitude

HarvardX



PREDICTIONX

Alyssa Goodman
Harvard-Smithsonian Center for Astrophysics
@aagie, #PredictionX



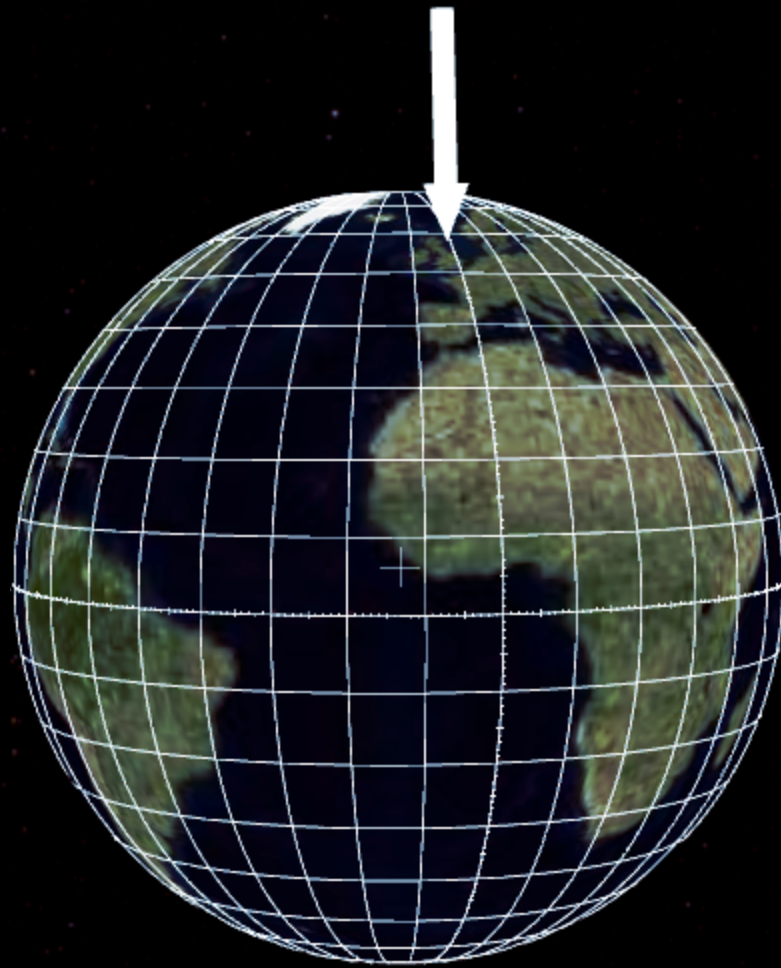
Latitude, Longitude,
and



WorldWide Telescope

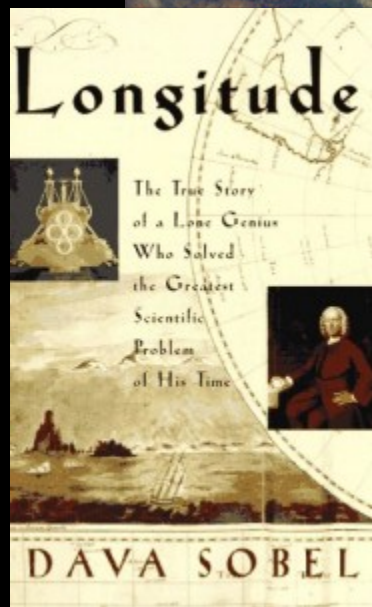
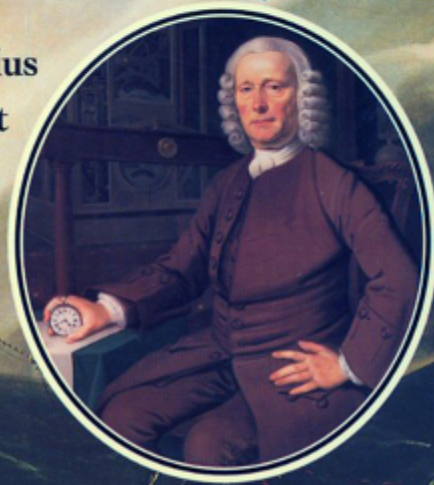


**But Longitude has no natural "zero."
Today, we use Greenwich, England.**



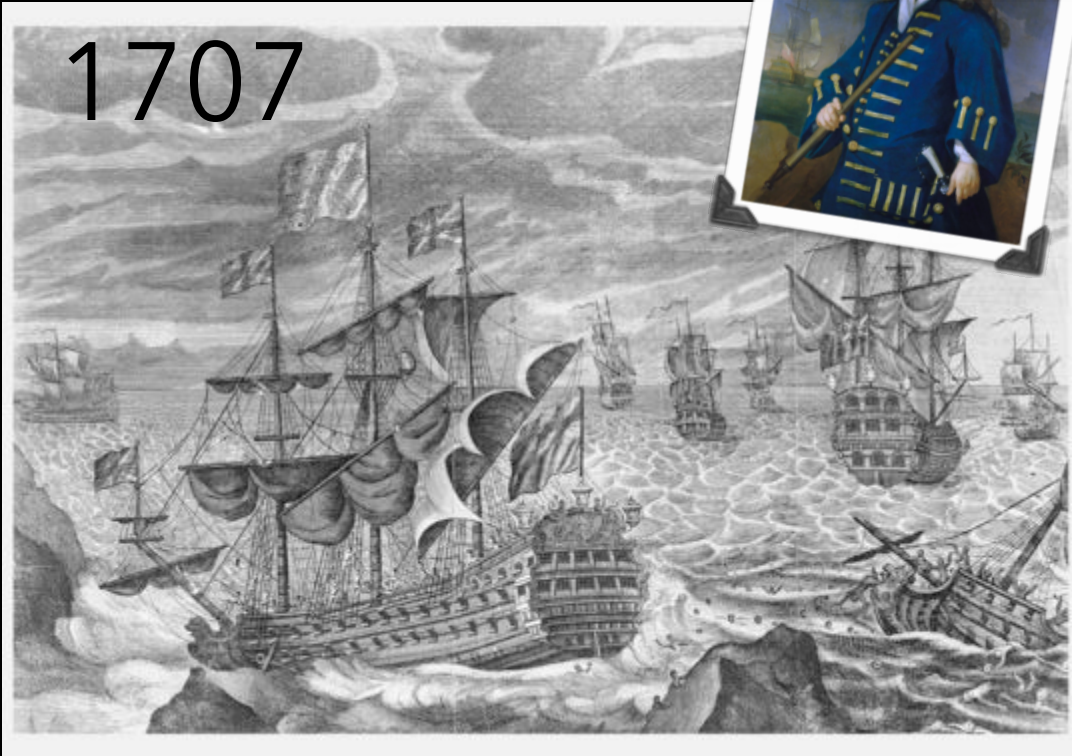
The Illustrated
Longitude

The True Story of a Lone Genius
Who Solved the Greatest
Scientific Problem
of His Time



DAVA SOBEL
AND
WILLIAM J. H. ANDREWES

1707



T-Mobile 4G 10:07 AM 38%

Personal Hotspot: 1 Connection



Isles of Scilly



2007



St. Mary's

Isles of Scilly
Heritage Coast

Hugh Town

Google



Isles of Scilly

Isles of Scilly, United Kingdom

Route

Isles of Scilly

Rome2rio

Hotels Cars About API Coverage Blog FAQ English USD

FROM Harvard University, 12 Oxford Stre TO Isles of Scilly, England

Add date for accurate airfares

Print view Explore

1 Fly
15hrs 03min **\$315 - \$757**

12 Harvard University
7min - 2013 feet

Harvard - Inbound
15min - every 10 minutes **\$3 - \$4**

South Station Silver Line -
15min - every 15 minutes **\$2 - \$3**

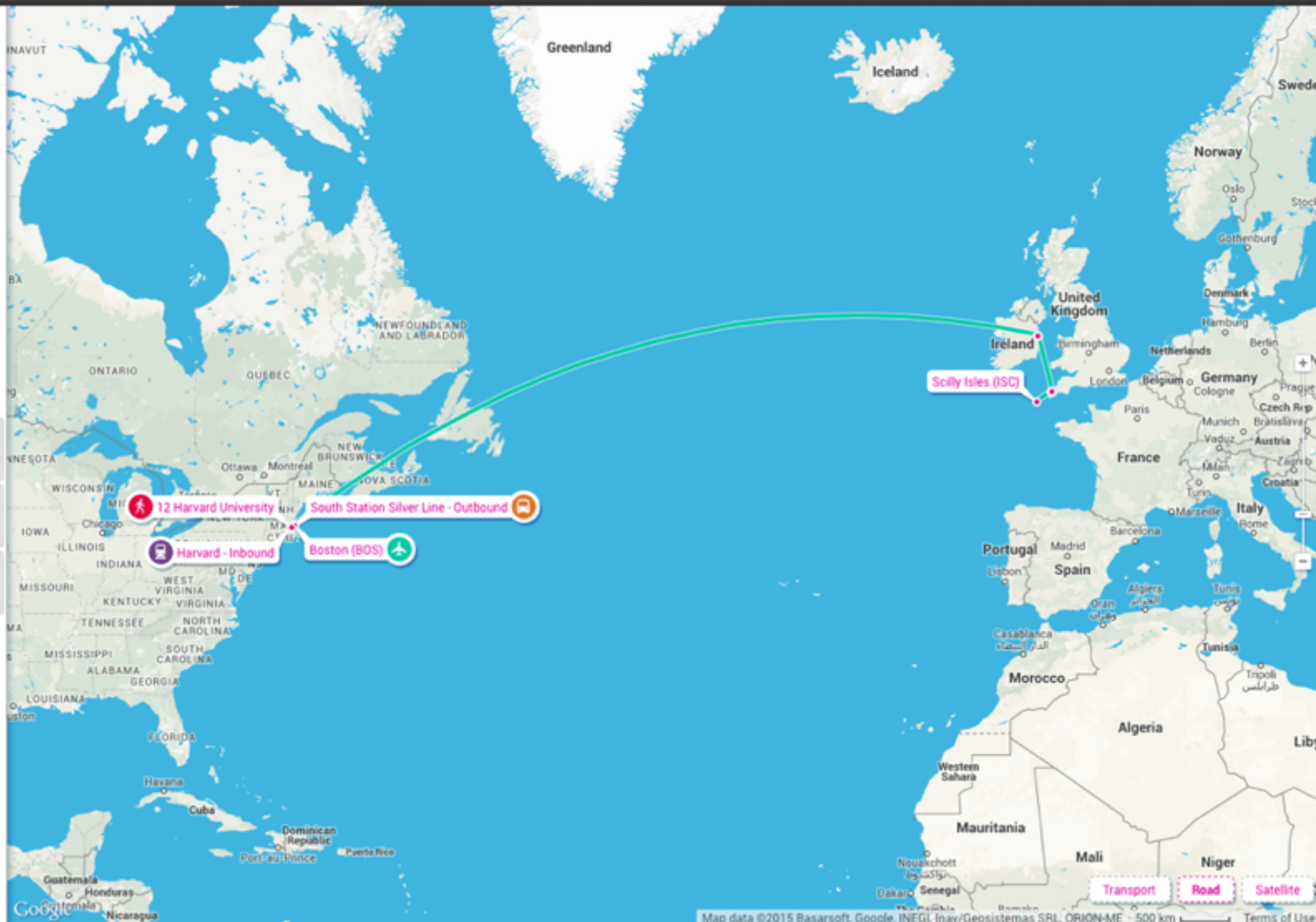
Boston (BOS)
12hrs 20min - 2 stopovers **\$310 - \$750**

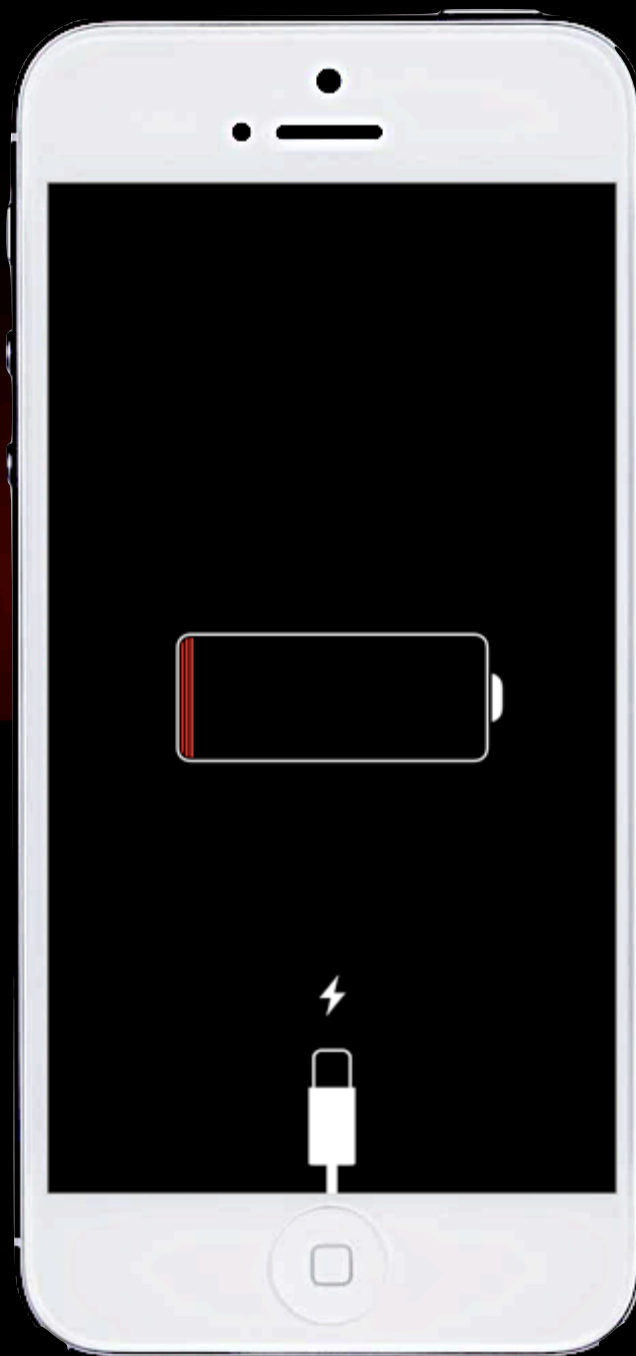
Scilly Isles (ISC) **7 Accommodations**

St Just Accommodation
Best Price Guarantee

Car Hire
Compare Best Rates

Things to do
View attractions

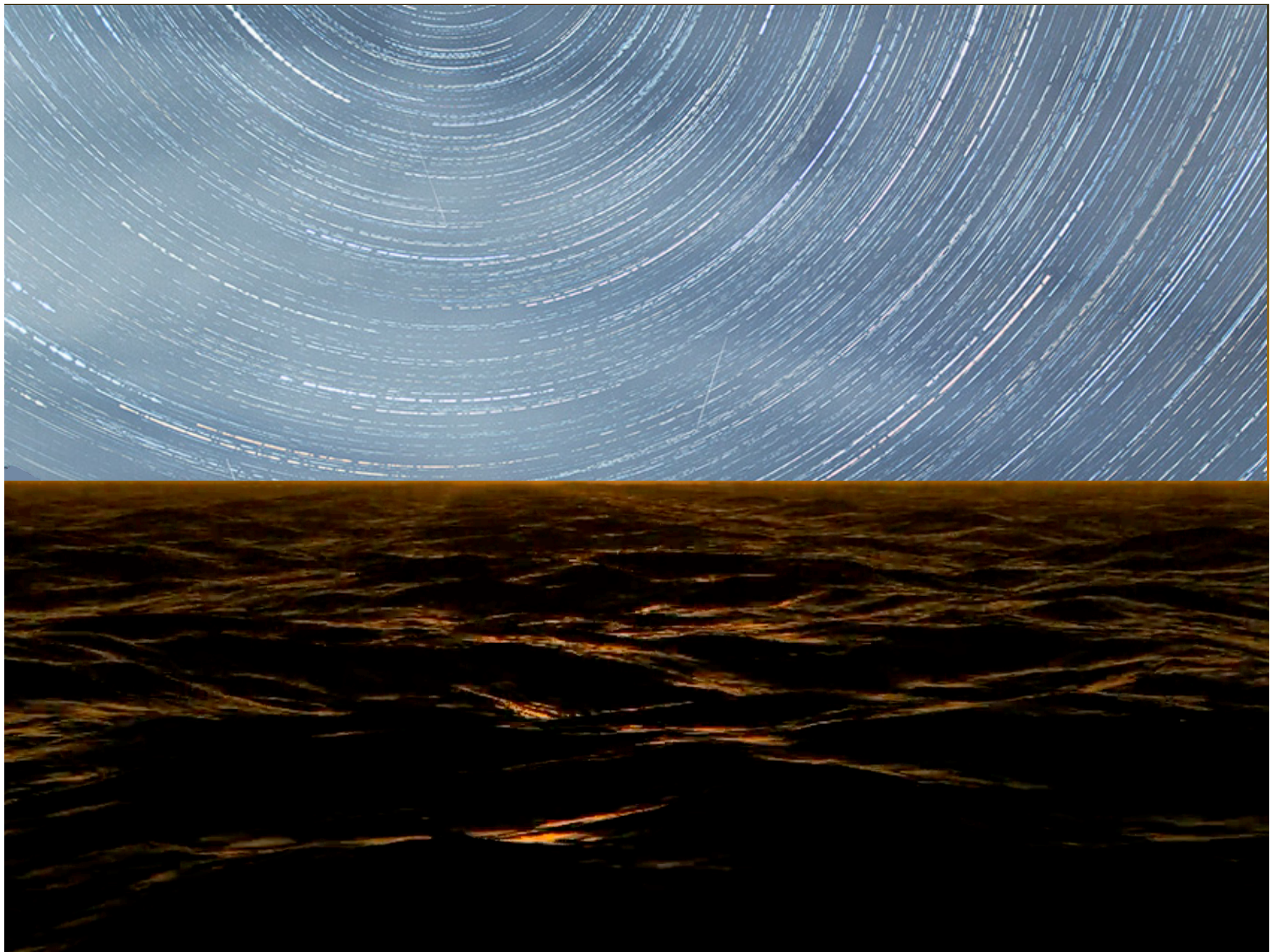




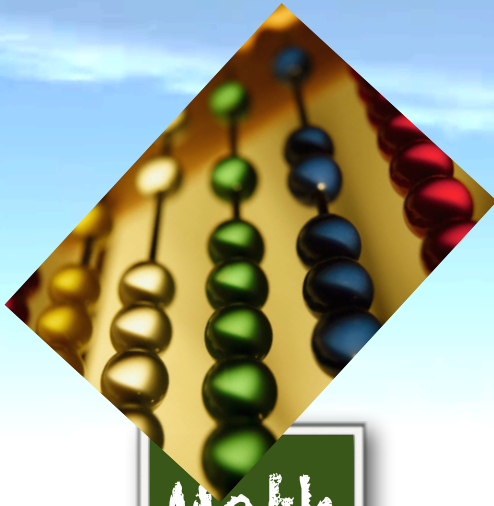


Skymarks

Landmarks



Elements of Navigation...at Sea



Math



SPEED



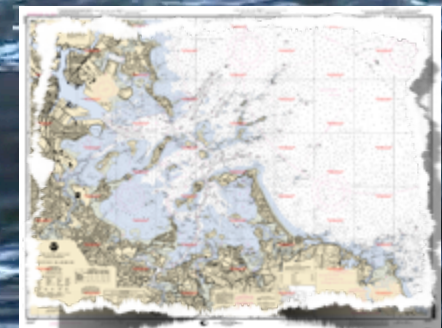
Astronomy



Timekeeping



Direction



Maps

Uncertainty

*Accuracy of
Maps*

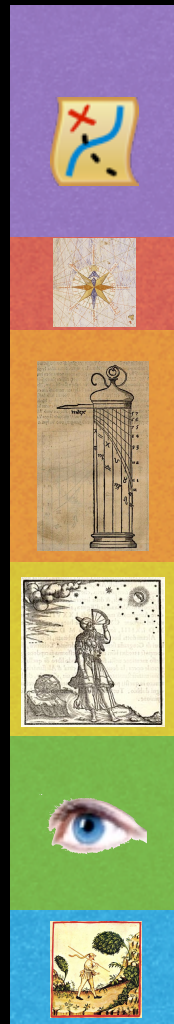
*Direction
Measurement*

*Time
Measurement*

*Angular
Measurement*

*Astronomical
Measurement*

*Measuring
Speed*



1200



1675



1750



2000

now

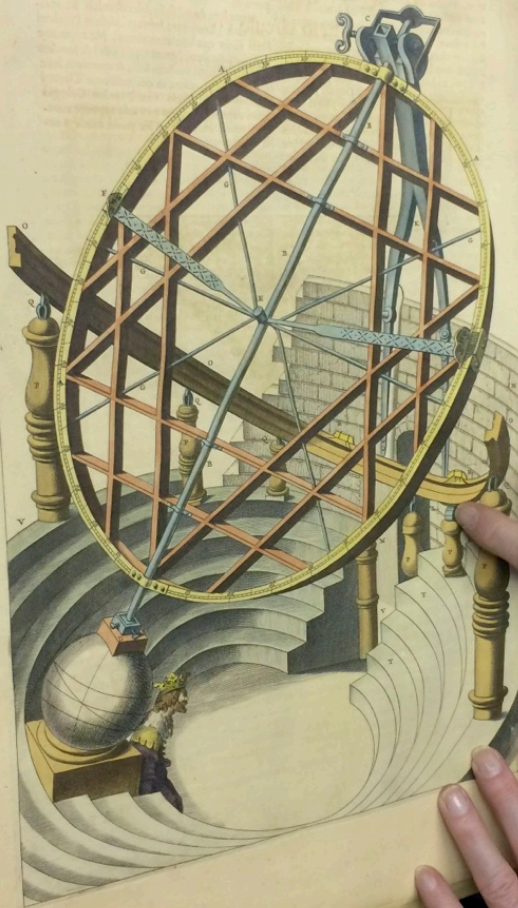


Harvard

Owen Gingerich's

copy, on May 12, 2015

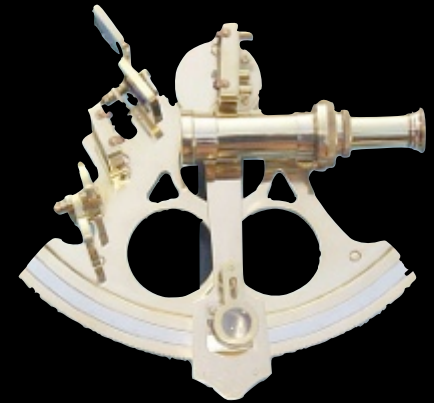
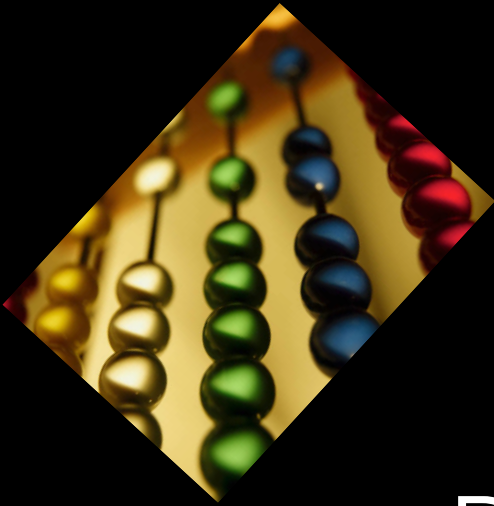
ARMILLÆ ÆQVATORIÆ MAXIMÆ
SESQVIALTERO



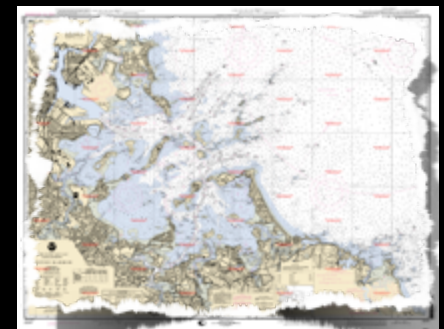
Per medium janua
Astronomi sunt in ma
que C. narrant, Co
ala regna illud de
suntis Tycho. A
solummentum vitru
videtur, quid sp
equis verba ea vno biblicam delin
rum per ante d. velle & exposit, (q
magno nobis conluerat) illi, de quo
fatis exacte interit, saltem illa
pollera de conluerat, alit quali
cauibus requiritur indigence, utpote
lummodo Armilla integra conuolu
tera fenestriculari quatuordecim. Quia
omnia, que de proutio dia, no
comuio, respiciunt, sed de longe pu
nulloque obstaculo, quod amittunt
runt, si prope spm Armilla Æq
fici debet eodemo. Tunc enim ante
para inuolui oblat, quomodo dicit
Declinationum Armilla prope spm
rem difficile de collatio, ut de illa q
impedimentum non dicam. Habem har
insuper paragonia, quod longe mag
fici videntur. Insuper Gratiu cum fia
his tempore alioque dicere exhiberi, de
stabilitate de conuoluio vna
aliquo facimus quatuordecim
hanc ingentium de ayru
larum hac est, que
tam in plano ter
tam Armil
habetur h
habetur h
tam vno
Dicit.

ARMILLÆ ÆQVATORIÆ MAXIMÆ
SESQVIALTERO CONSTANTES CIRCULO.





Dead Reckoning



“Once they were out of sight of land...”



from: The Clock That Changed the World (BBC History of the World)

presenter: Adam Hart-Davis; <https://www.youtube.com/watch?v=T-g27KS0yiY>

Latitude is "Easy"...

Earth, Sun and Stars

The Earth **spins** on its axis, once per ~24 hours.

Earth's **spin** causes distant stars to appear to go in **circular paths** (as if painted on to a very distant sphere).

Earth's spin axis is **tilted** by 23 degrees from the plane of its orbit.

Because of the tilt, the rise, **transit**, and set times for a star whose path dips below the horizon **depends** on where the Earth is in its orbit (**on date**).

The value of the maximum **altitude** (at transit) any star reaches on a particular day **depends on latitude**. (+Altitude of North Star=Latitude.)

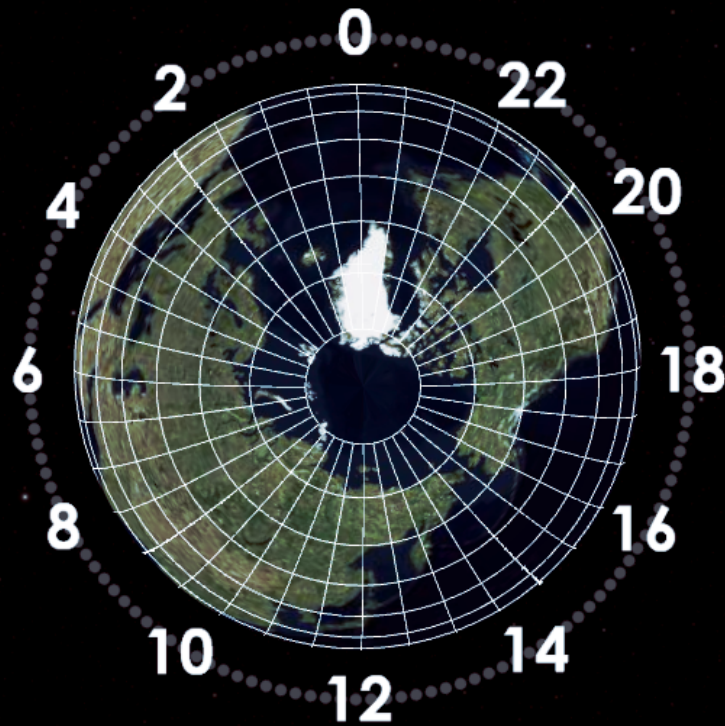
A star will reach **its maximum altitude ("transit")**, at the *same* (local) time on any given day, as viewed from any place with equal latitude.

Earth, Sun and Stars

The Earth **spins** on its axis, once per ~24 hours. 

1 Rotation per 24 Hours means

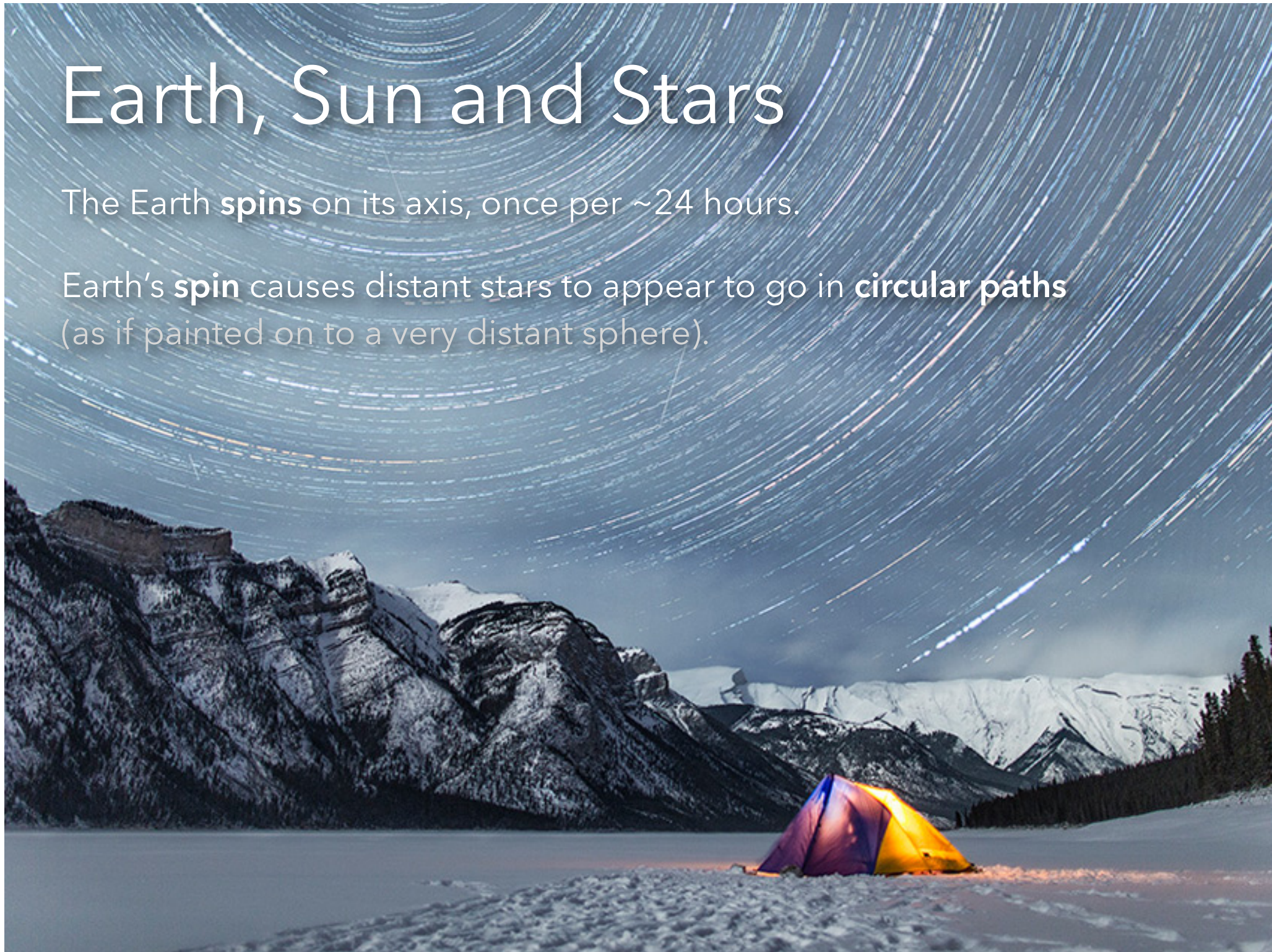
15 degrees of longitude=1 hour



Earth, Sun and Stars

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Earth, Sun and Stars

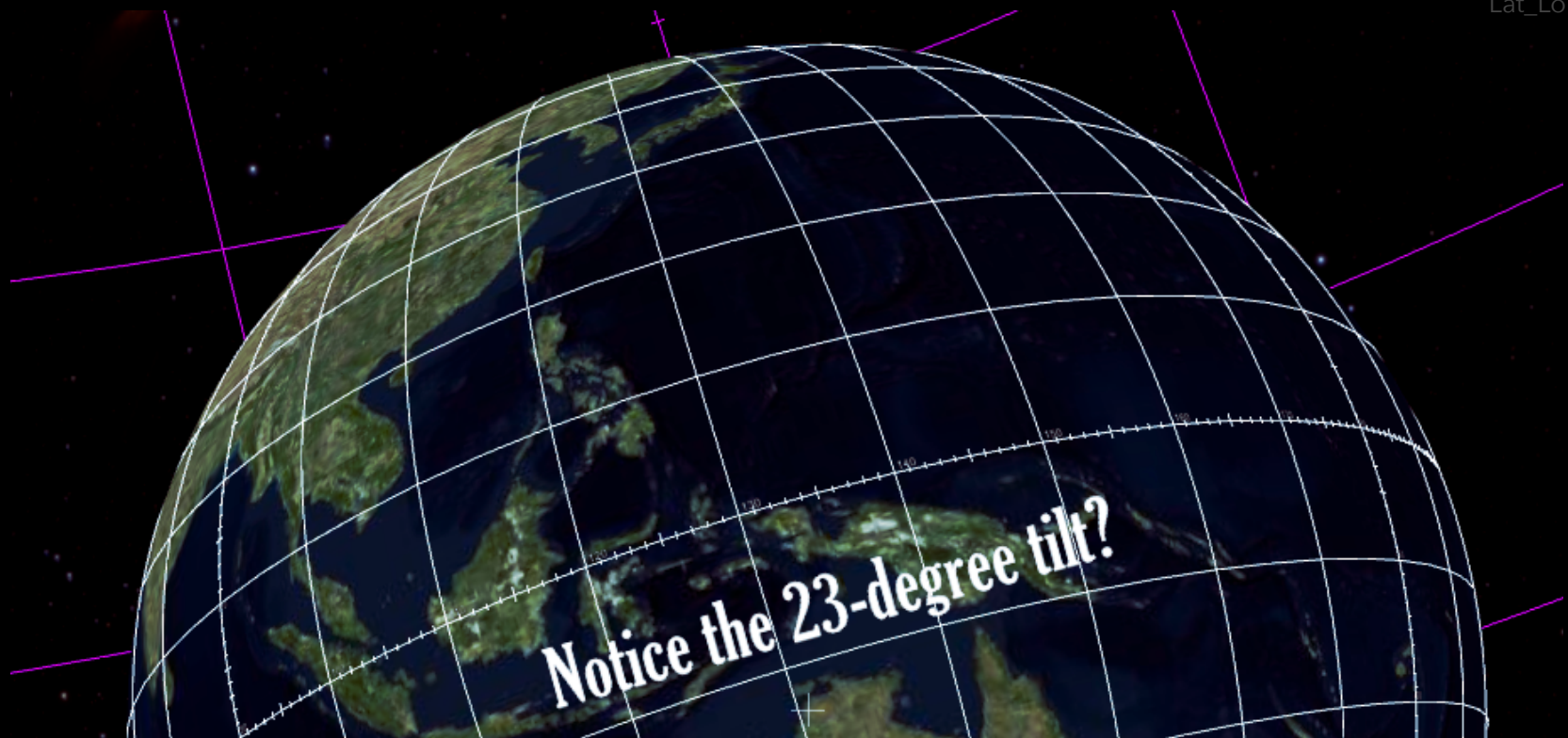
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Lat_Long_HMNH3.wtt



Earth, Sun and Stars

The Earth **spins** on its axis, once per ~24 hours.

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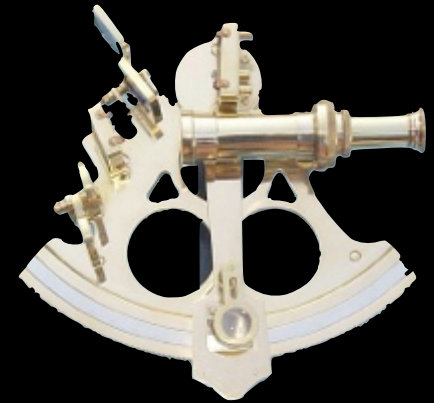
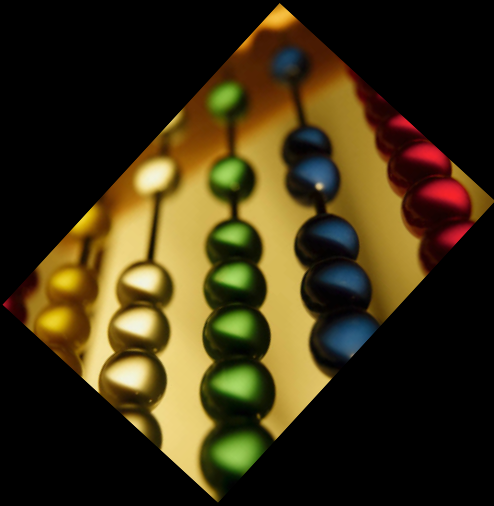
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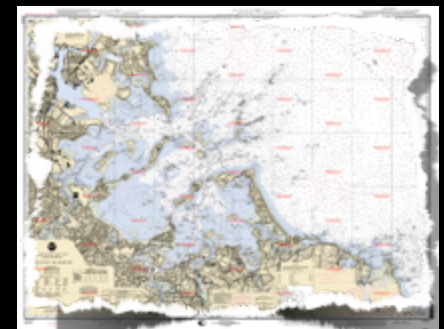
The value of the maximum **altitude** (at transit) any star reaches on a particular day **depends on latitude**. (+Altitude of North Star=Latitude.)



[demo]



"Sail the Parallel"



Earth, Sun and Stars

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A star will reach **its maximum altitude ("transit")**, at the *same* (local) time on any given day, as viewed from any place with equal latitude.

Earth, Sun and Stars

The value of the maximum **altitude** (at transit) any star reaches on a particular day **depends on latitude**. (+Altitude of North Star=Latitude.)

Great! We can easily use the stars to find latitude.

A star will reach **its maximum altitude ("transit")**, at the *same* (local) time on any given day, as viewed from any place with equal latitude.

Drat! We can only use the stars to find longitude if we know the time, very well.

Uncertainty → Tragedy

*Accuracy of
Maps*

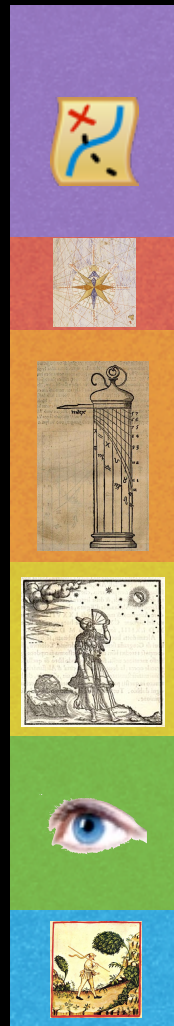
*Direction
Measurement*

*Time
Measurement*

*Angular
Measurement*

*Astronomical
Measurement*

*Measuring
Speed*



1200



1675



1750



2000

now



The Longitude Act



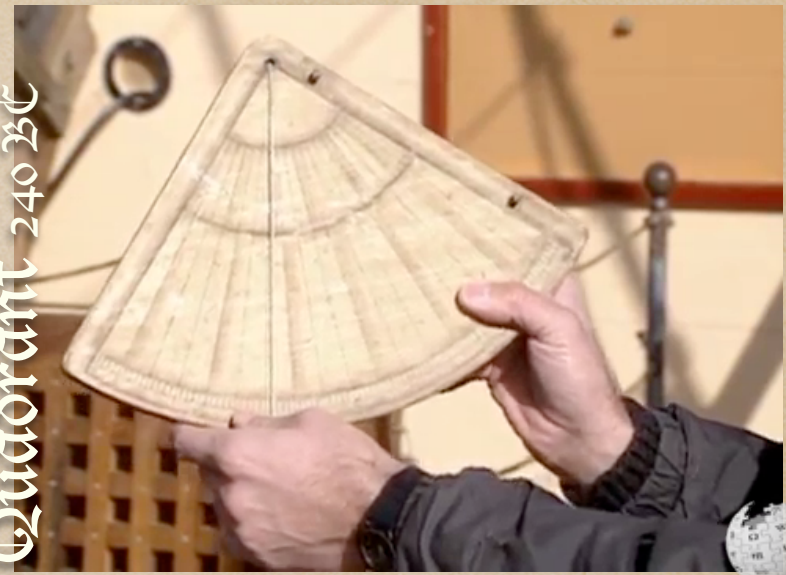
from: The Clock That Changed the World (BBC History of the World)

presenter: Adam Hart-Davis; <https://www.youtube.com/watch?v=T-g27KS0yiY>

Measuring Astronomical Objects' Positions



Cross Staff 1432



Quadrant 240 BC



Astrolabe 1500

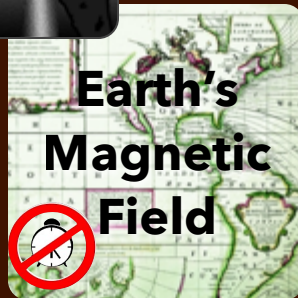


Backstaff 1594

Finding Longitude

...use the stars to find **longitude** if we know the **time**, very well...

Hard



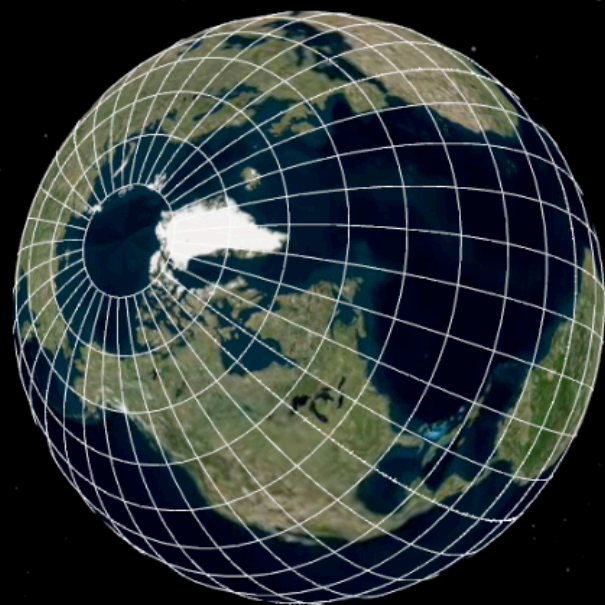
Crazy



Simple



Time-based navigation relies on known speed...
of Earth's rotation.





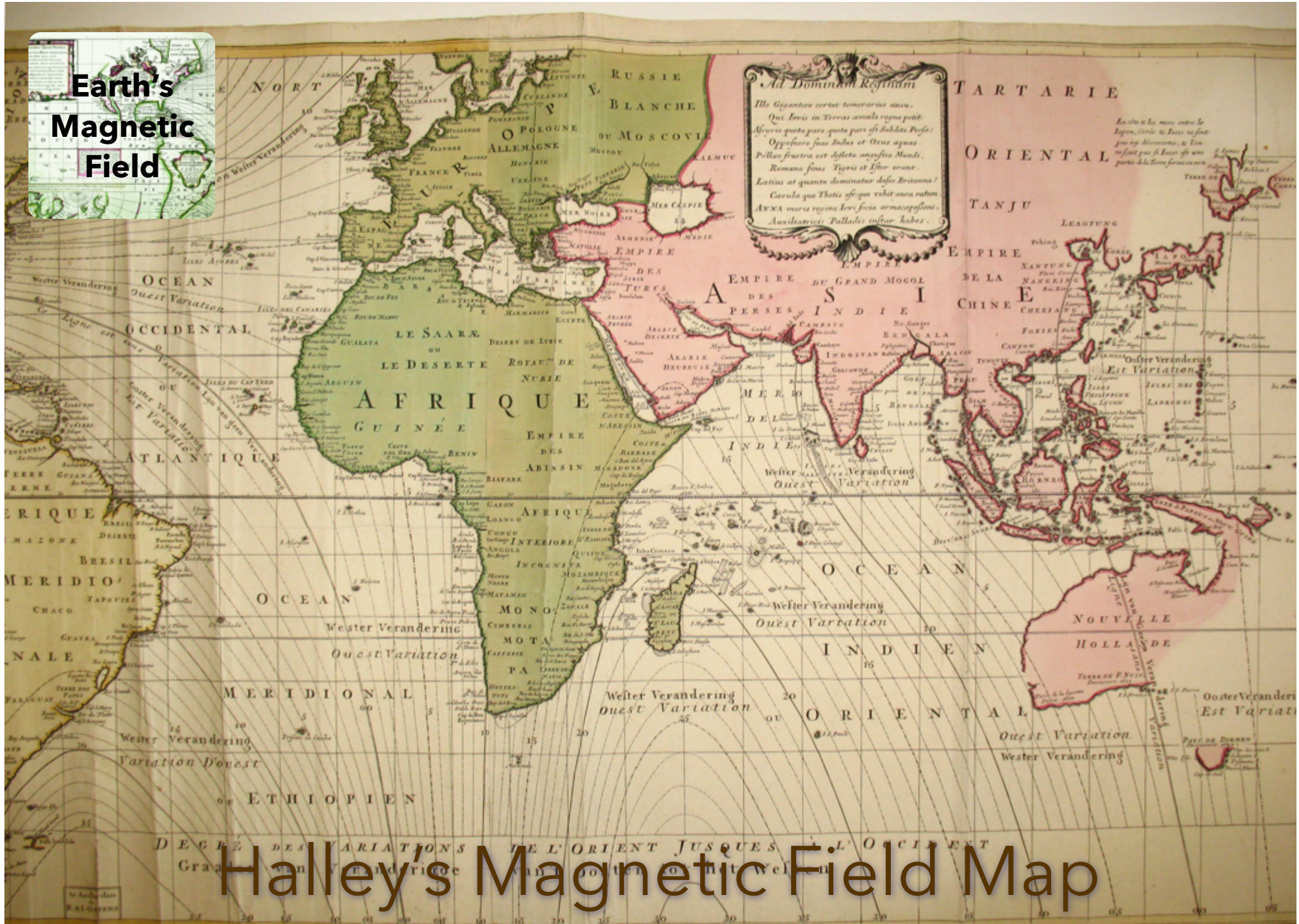
scene from "The Longitude", reproduced from YouTube, without permission
<https://www.youtube.com/watch?v=XUhhdwvLuyk>



scene from "The Longitude", reproduced from YouTube, without permission
<https://www.youtube.com/watch?v=XUhhdwvLuyk>



Earth's
Magnetic
Field



Ad Dominum Regium
Ille Gigantes certis temerarius ausu,
Qui Lewis in Terras amala regna petit,
Nec non quatuor parte pars est Indiarum Perse!
Opposuit fatis Indus et Oceanus aquas,
Pellat frustra est delecta angustia Mundi,
Romana fides Tyrus et Ister arant.
Latius at quanto dominatur dabo Britannia!
Certe qui Thetis effugit velut aura ratem
ANNA maris regina levi fœca armacopifera,
Amphitruoni Palladis instar habes.

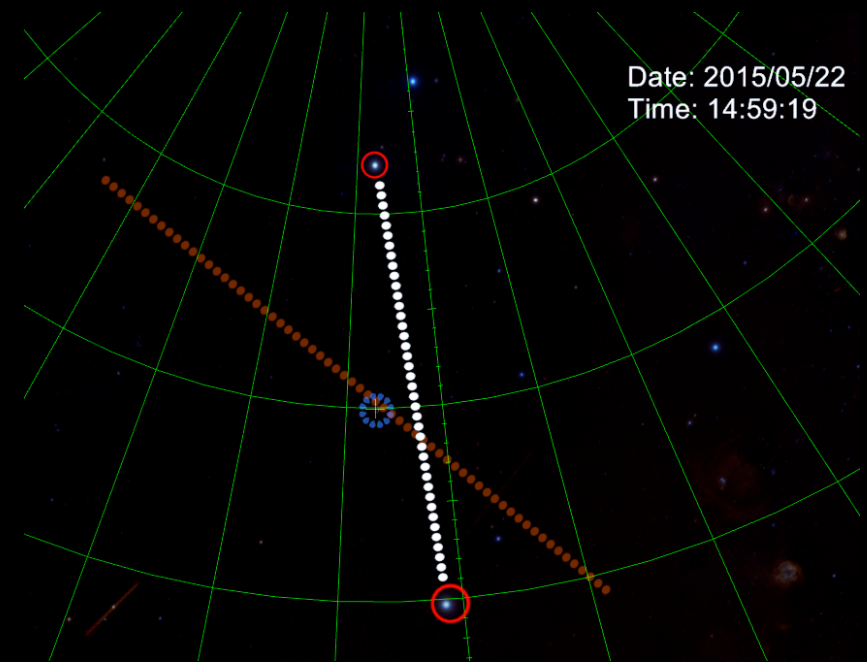
Halley's Magnetic Field Map



The "Lunar Distance Method"

To find time: Calculate the exact path of the moon, as a function of time, read off position, calculate time.

Complications: Relies on VERY accurate records, predictions, measurements and calculations.



moon_star_motions.wtt

lunars_hard.wtt

Galileo & Jupiter's Moons



To find time: Calculate the positions of Jupiter's moons as a function of time. Observe moons, know time.

Complications: Relies on high-resolution observations, requiring a very stable observing platform (not a ship!!)



Galileo.wtt





Galileo Galilei (1564-1642)



Sec^{us} Principale

Galileo Galilei, Humilis^s Servus della Ser.^{na} V.^{na} invigilantissima
Repubblica, et di ogni spirito di potere non solo sacrificato
alvario che nome della Lettera di Matematicis nelle Scuole
di Padova,

Inviare d'ausore determinato di presentare al Ser.^{no} Principe
l'Utile et il piacere di giuamenti inestimabile di ogni
regione et in terra marittima o terrestre senza di tenere per
no nuovo artificio nel maggior profitto et utilità a disposizione
di V.^{ra} Ser.^{na} l'Utile cavato dalle più et diute speculazioni di
prophetia in l'vantaggio di scoprire le parti et Velle dell' inimica
di Vae hore et più di tempo prima et più sopra noi et distinguendo
il numero et la qualità dei Vasselli giudicare la più forte
pallesirsi alla caccia al combattimento o alla fuga, o pure anzi
nella campagna spista vedere et particolarmente distinguere ogni suo
movto et provvedimento.

Adi 7. di Gennaio
Gione si vede così

Adi 8. così

Adi 12. si vede in tale disposizione

*Adi 13. si vedono miris^s a Gione 4 Stelle **

Adi 14. è angelo

Adi 15. si vede la pros^a a 7. ora in mig^s la 4. ora di

spazio della 3.^a coppia l'una

Lo spazio delle 3. sudorali nel con
magine del diametro di 7. et di
10. in linea retta.

7	* ○ *	17	* ○
8	○ * *	18	* ○
10	* * ○	19	* ○ * *
11	* * ○	19	* ○ * *
12	* ○ *	20	○ * ○ ○
13.	* ○ * *	21	... ○ *
15	○ * * *	22	* ○ * *
15	○ * *	22	○ * *
16	○ *	23	* ○ *
17	* ○ *	24	* ○
		24	* ○

SIDEREUS NUNCIUS

On the third, at the seventh hour, the stars were arranged in this
sequence. The eastern one was 1 minute, 30 seconds from Jupiter
; closest western one 2 minutes; and the other western one wa

ast * ○ * * West

o minutes removed from this one. They were absolutely on the
ame straight line and of equal magnitude.

On the fourth, at the second hour, there were four stars around
upiter, two to the east and two to the west, and arranged precisely

East * * ○ * * West

on a straight line, as in the adjoining figure. The easternmost wa
istant 3 minutes from the next one, while this one was 40 second
rom Jupiter; Jupiter was 4 minutes from the nearest western one
d this one 6 minutes from the westernmost one. Their magnitude
ere nearly equal; the one closest to Jupiter appeared a little smaller
an the rest. But at the seventh hour the eastern stars were only
0 seconds apart. Jupiter was 2 minutes from the nearer eastern

East ** ○ * * West

one, while he was 4 minutes from the next western one, and this
one was 3 minutes from the westernmost one. They were all equal
and extended on the same straight line along the ecliptic.

On the fifth, the sky was cloudy.

On the sixth, only two stars appeared flanking Jupiter, as is seen

East * ○ * West

n the adjoining figure. The eastern one was 2 minutes and the
western one 3 minutes from Jupiter. They were on the same straight
line with Jupiter and equal in magnitude.

On the seventh, two stars stood near Jupiter. both to the east.

Notes for & re-productions of Sidereus Nuncius



Galileo & Jupiter's Moons



GALILEO'S "NEW ORDER"

Created by Alyssa Goodman, Curtis Wong and Pat Udomprasert,
with advice from Owen Gingerich and David Malin



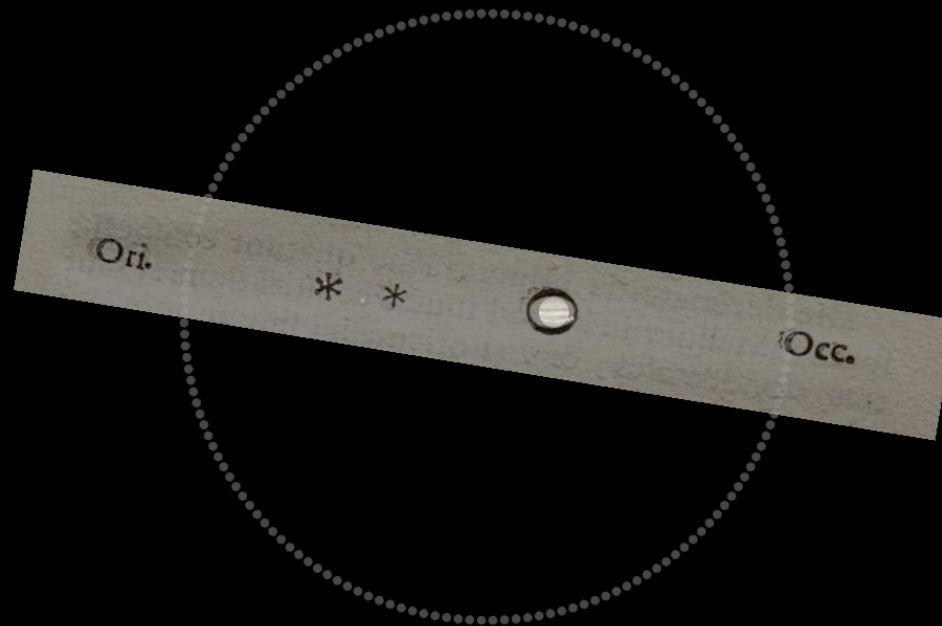
*Galileo's New Order, A WorldWide Telescope Tour by Goodman, Wong & Udomprasert 2010
Microsoft Research WWT Software (~now "OpenWWT"): Wong (inventor), Fay (architect), et al.*



Galileo & Jupiter's Moons



January 11, 1610

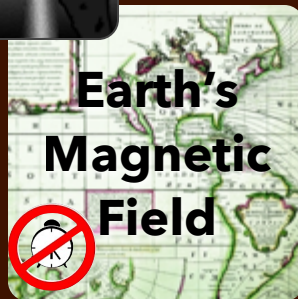


*Galileo's New Order, A WorldWide Telescope Tour by Goodman, Wong & Udomprasert 2010
Microsoft Research WWT Software (~now "OpenWWT"): Wong (inventor), Fay (architect), et al.*

Finding Longitude

...use the stars to find **longitude** if we know the **time**, very well...

Hard



Crazy



Simple

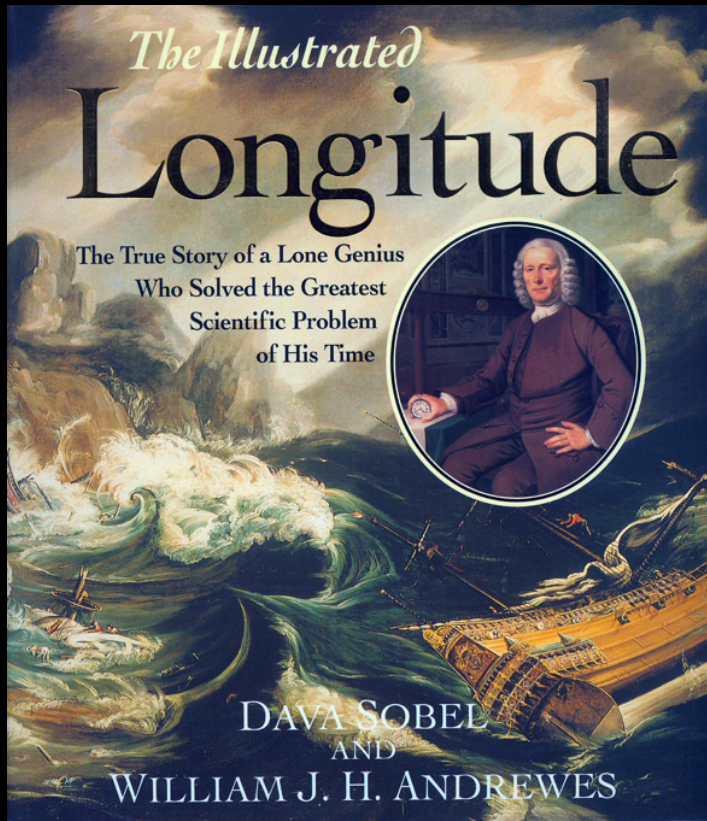


“do it with a clock...”



from: The Clock That Changed the World (BBC History of the World)

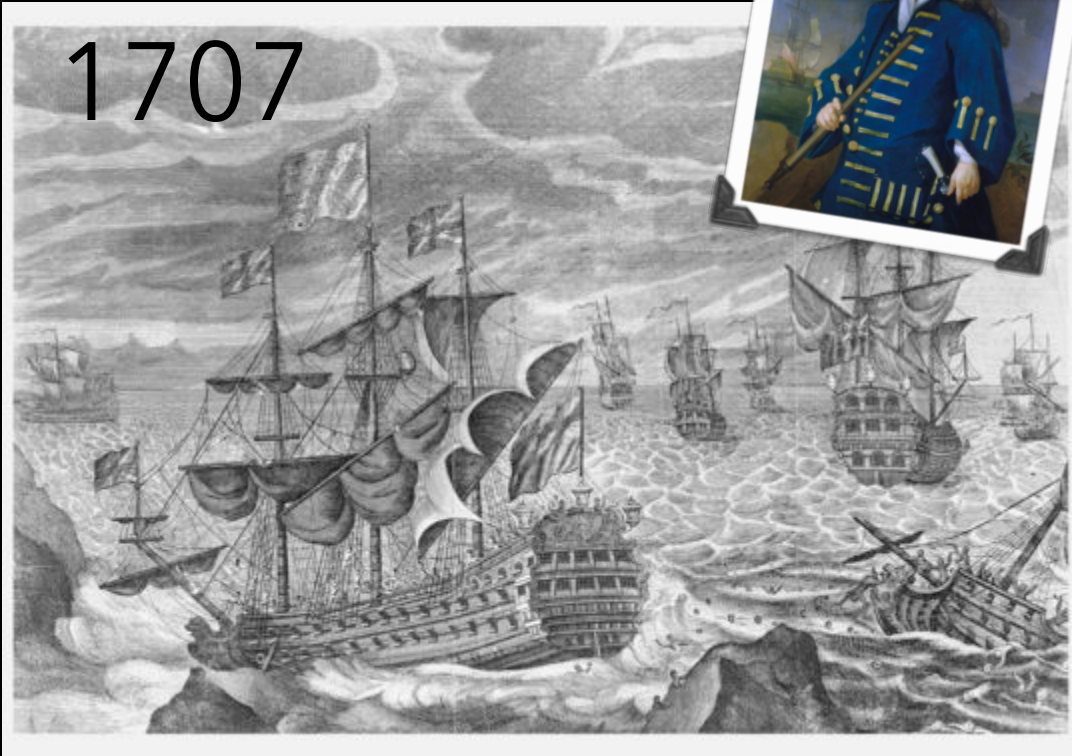
presenter: Adam Hart-Davis; <https://www.youtube.com/watch?v=T-g27KS0yiY>



"H4"



1707



T-Mobile 4G 10:07 AM 38%

Personal Hotspot: 1 Connection

Isles of Scilly

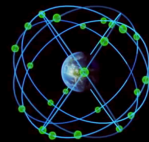
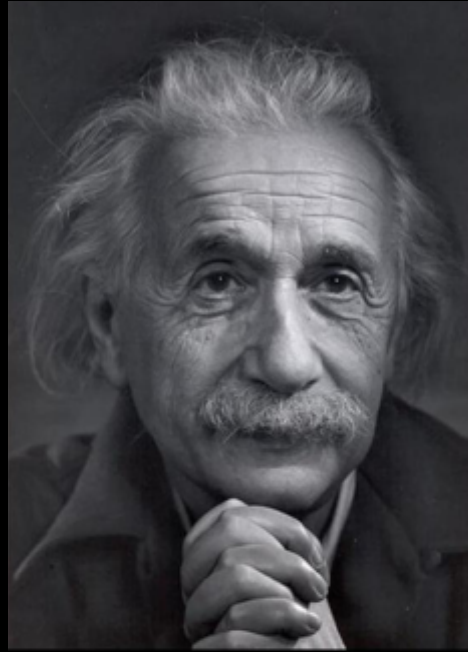


2007

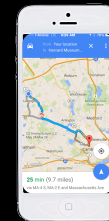
Isles of Scilly

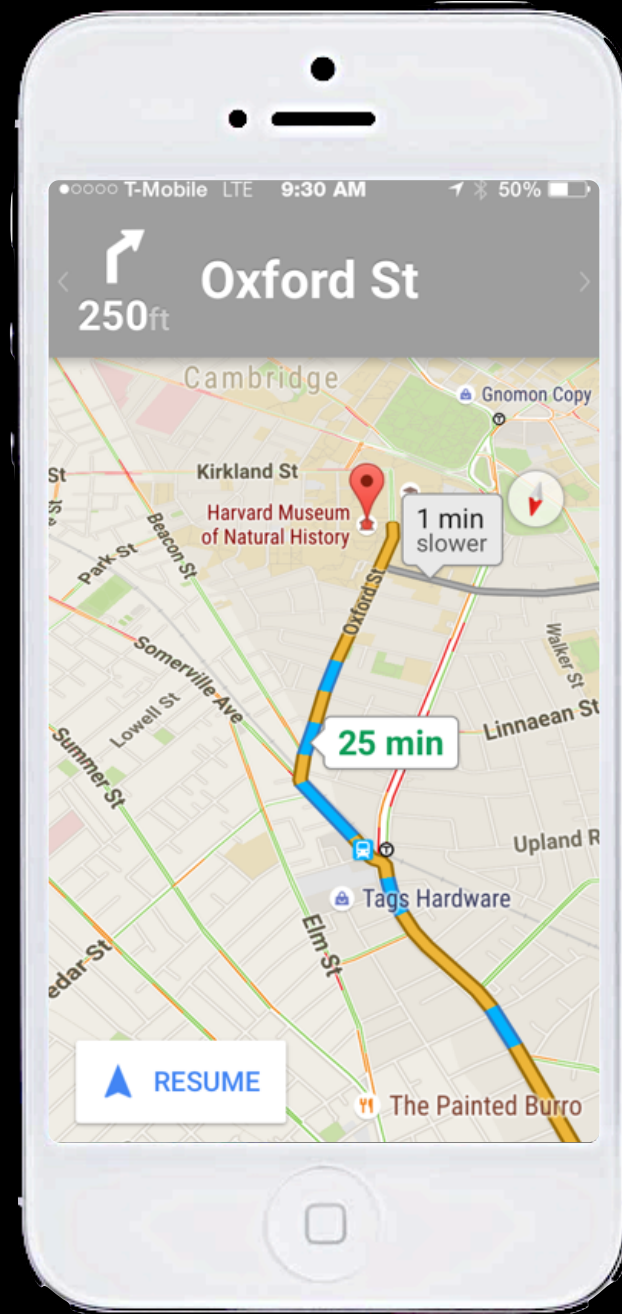
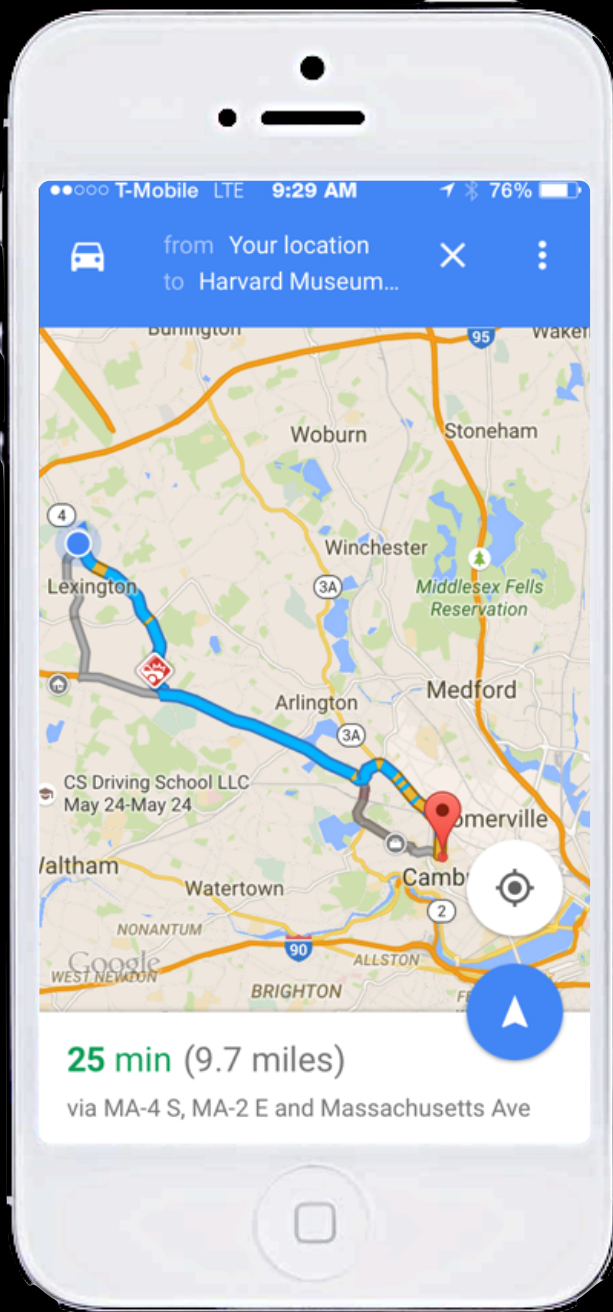
Isles of Scilly, United Kingdom

Route

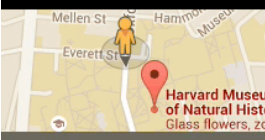


Einstein (, Jobs) & GPS



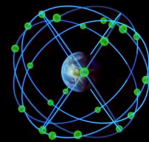
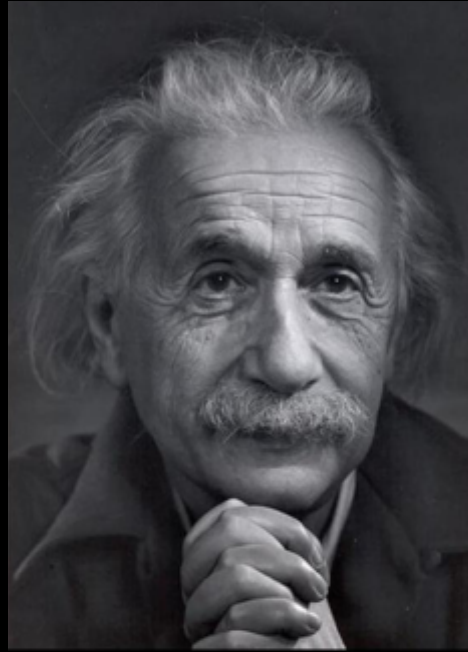


44 Oxford St
Cambridge, Massachusetts
Street View - Sep 2014

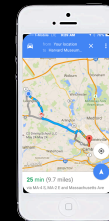


Back to Map

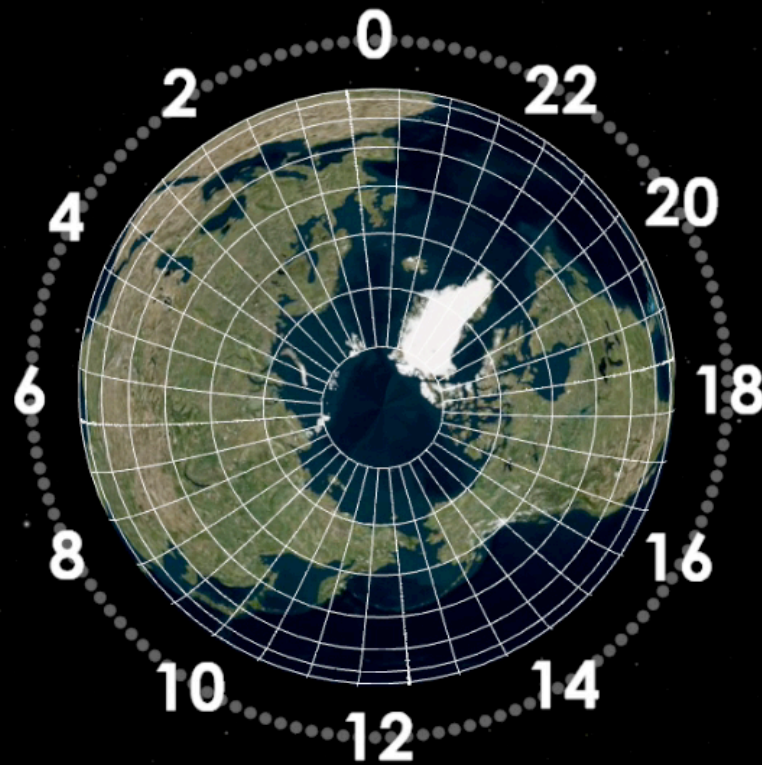




Einstein (, Jobs) & GPS

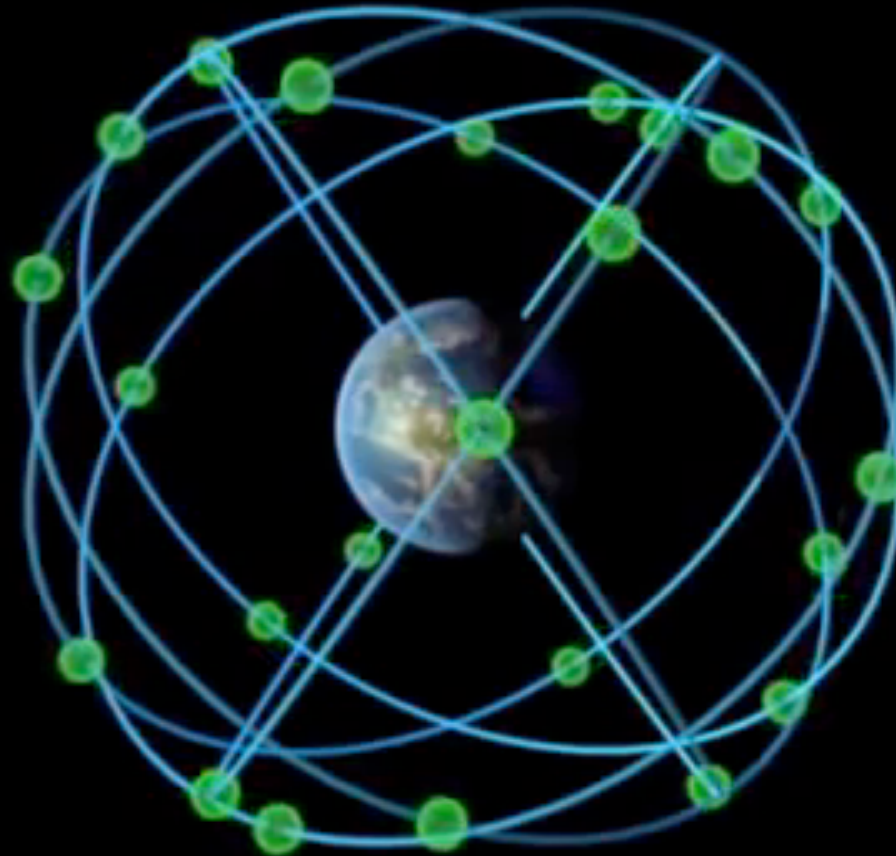


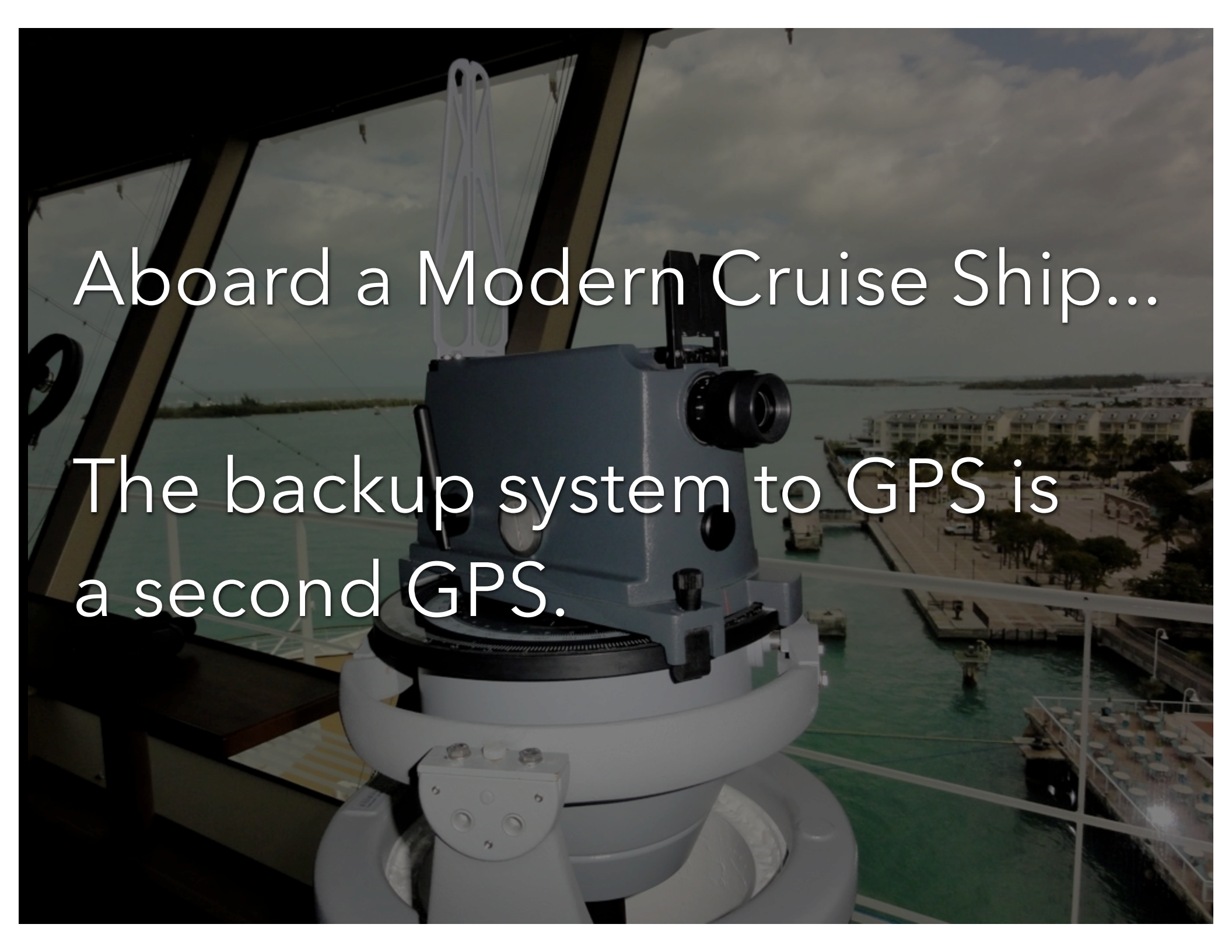
Time-based navigation relies on known speed...
of Earth's rotation.



shown at 2 hours per second elapsed on-screen

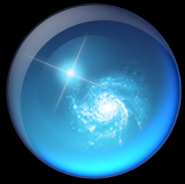
GPS also relies on known speed...of light



A photograph of a modern cruise ship's bridge. In the foreground, a large, light-colored sextant is mounted on a pedestal. The background shows a harbor with buildings, a dock, and a body of water under a cloudy sky. The image is dimmed to allow text to be overlaid.

Aboard a Modern Cruise Ship...

The backup system to GPS is
a second GPS.



Open WorldWide Telescope

worldwidetelescope.org

The screenshot shows the Open WorldWide Telescope interface. At the top, there is a navigation bar with tabs for 'Explore', 'Guided Tours', 'Search', 'View', and 'Settings'. Below this, a 'Collections' menu shows 'All-Sky Surveys' with a list of survey thumbnails: Digitized Sky Survey, VLSS: VLA Low-frequency Sky Survey, WMAP ILC 5-Year Temperature Anisotropy Maps, SFD Dust Map (Infrared), IRIS: Improved Resolution Images, 2MASS: Two Micron All Sky Survey, and Hydrogen Alpha Filter. The main view is a 3D sky model with a central 'Finder Scope' showing a 'Spiral Galaxy In Andromeda' (NGC224). A 'Context bar' at the bottom shows 'Andromeda' and 'Three Faces of M31'. A 'Context globe' shows the current field of view. A 'Look At' panel shows 'Sky' and 'Andromeda'. A 'Finder Scope' panel shows 'Classification: Spiral Galaxy In Andromeda' and 'NGC224' with coordinates: RA: 00h42m42s, Dec: 41:16:00, Distance: 70:06:26, Rise: 275:42:17, Transit: 00:35. A 'Context bar' shows 'Andromeda' and 'Three Faces of M31' with coordinates: RA: 00h42m40s, Dec: 41:13:35. A 'Context globe' shows the current field of view. A 'Look At' panel shows 'Sky' and 'Andromeda'. A 'Finder Scope' panel shows 'Classification: Spiral Galaxy In Andromeda' and 'NGC224' with coordinates: RA: 00h42m42s, Dec: 41:16:00, Distance: 70:06:26, Rise: 275:42:17, Transit: 00:35. A 'Context bar' shows 'Andromeda' and 'Three Faces of M31' with coordinates: RA: 00h42m40s, Dec: 41:13:35. A 'Context globe' shows the current field of view.

Seamlessly explore imagery from the best ground and space-based telescopes in the world

Expert led tours of the Universe

Control time to study how the night sky changes

View and compare images from across the electromagnetic spectrum

Much more than "just" the sky at night! 3D features can take you to other planets, stars & galaxies.

Finder Scope links to Wikipedia, publications, and data, so you can learn more

Context bar shows items of interest in current field of view

Context globe shows where you're looking.



Lost without Longitude

HarvardX



PREDICTIONX







Alyssa Goodman
Harvard-Smithsonian Center for Astrophysics
@aagie, #PredictionX

extra slides

solar-sidereal off by 2 min for 180 deg of longitude difference







Time Zone: UT +/- 0 h | Daylight S. T.: | Location: User Input | Lat. xx.xx: 10 | Long. xx.xx: 0 | Run:

Local Time (h:m): 19:00 | Date: 2015 May 15

 UT 19:00:00 2015 Fri 15 May 19:00:00	 10:32:44.8 Greenwich Sidereal Time	Julian Day 2457158.29167 System Clock: UT - 4 h DST may be active GHA Aries 158.19°
 19:00:00 Zone Time	 10:32:44.8 Local Sidereal Time	Location: User Input Latitude 10.0° N Longitude 0.0° E Sunrise 05:39 Hrs Culmination 11:56 Hrs Sunset 18:14 Hrs Equation of Time + 3 min 39 s Longitude Offset +0 min 00 s LHA Aries 158.19° 2015 May 15 Fri 19:00:00
 19:03:39 Local Solar Time	 19:03:39 Greenwich Solar Time	Local Sid. Time 158.19° Local Hour Angle 105.91° Greenwich H. A. 105.91° Sun R. A. 3h 29m 8s 52.28° Zone - Solar -3.6 min Sidereal & Solar Clock 0.98 © 2003-2013 J. Giesen www.GeoAstro.de

Time Zone: UT +/- 0 h | Daylight S. T.: | Location: User Input | Lat. xx.xx: 10 | Long. xx.xx: 179.99 | Run:

Local Time (h:m): 19:00 | Date: 2015 May 15 | Now

 UT 19:00:00 2015 Fri 15 May 19:00:00	 10:32:44.8 Greenwich Sidereal Time	Julian Day 2457158.29167 System Clock: UT - 4 h DST may be active GHA Aries 158.19°
 19:00:00 Zone Time	 22:32:42.4 Local Sidereal Time	Location: User Input Latitude 10.0° N Longitude 179.99° E Sunrise 17:39 Hrs Culmination 23:56 Hrs Sunset 06:14 Hrs Equation of Time + 3 min 39 s Longitude Offset +719 min 58 s LHA Aries 338.18° 2015 May 15 Fri 19:00:00
 07:03:36 Local Solar Time	 19:03:39 Greenwich Solar Time	Local Sid. Time 338.18° Local Hour Angle 285.9° Greenwich H. A. 105.91° Sun R. A. 3h 29m 8s 52.28° Zone - Solar -723.6 min Sidereal & Solar Clock 0.98 © 2003-2013 J. Giesen www.GeoAstro.de

Greenwich solar-sidereal= 8h 31m 54.2 s

local solar-sidereal=8 h 29 m 53.6s

Sidereal time is the **right ascension** of stars on your local meridian at any moment.

