

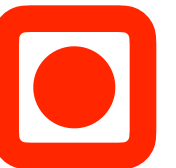
**harmonoia:** *n.* an itchy sense of dread when life feels just a hint too peaceful—when everyone seems to get along suspiciously well, with an eerie stillness that makes you want to brace for the inevitable collapse, or burn it down yourself.

From harmony + paranoia. Pronounced “hahr-muh-*noi*-uh”

– John Koenig,  
The Dictionary of Obscure Sorrows

# The Longitude Problem

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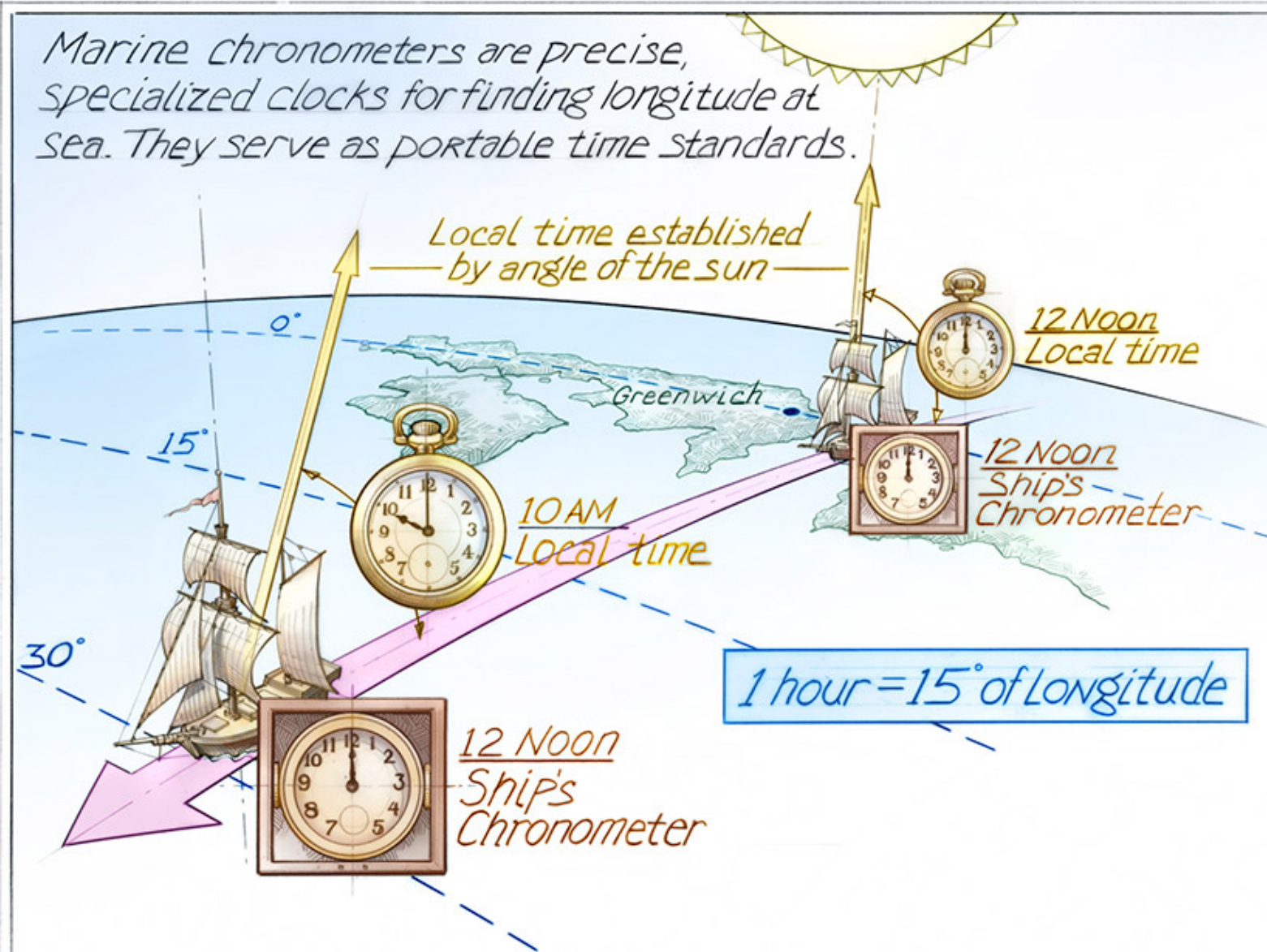




Charlie Loyd  
Himawari-8

## USING A MARINE CHRONOMETER

Marine chronometers are precise, specialized clocks for finding longitude at sea. They serve as portable time standards.



# Simultaneous observations

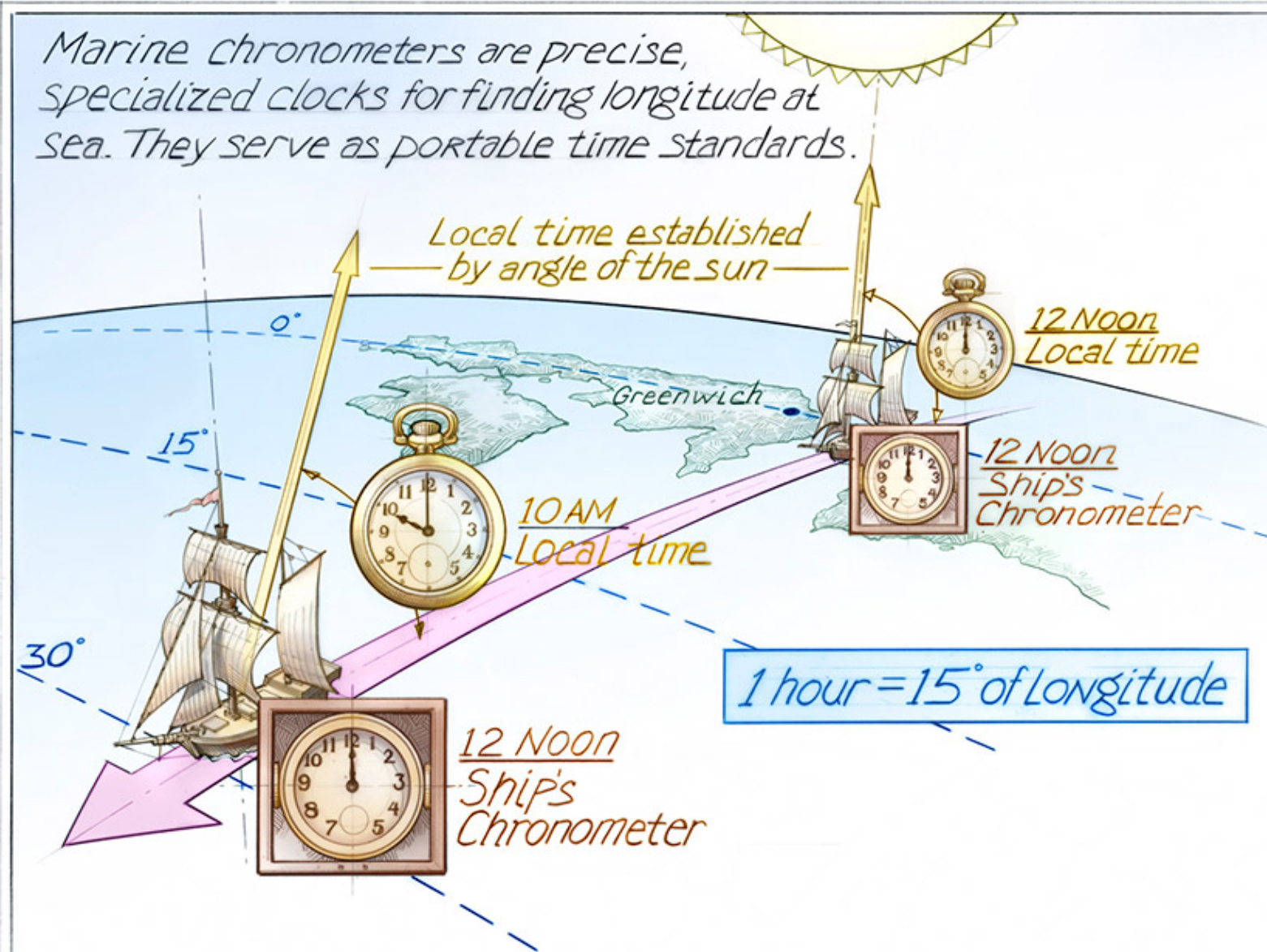
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- If two observers see where the stars (or sun) are above the eastern horizon at same time, they can determine their longitude
- But all measurements of the time (stars, sun) are local
  - Can be rephrased as difference in local time provides difference in longitude
- Problem is how to know observations are happening simultaneously



## USING A MARINE CHRONOMETER

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Things that almost work



# Wait for a lunar eclipse

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# Lunar eclipse

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- Was used in ancient times
- Too rare for use at sea
- Hard to use accurately (when did it start, etc.)

# Galilean moons

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# Galilean moons

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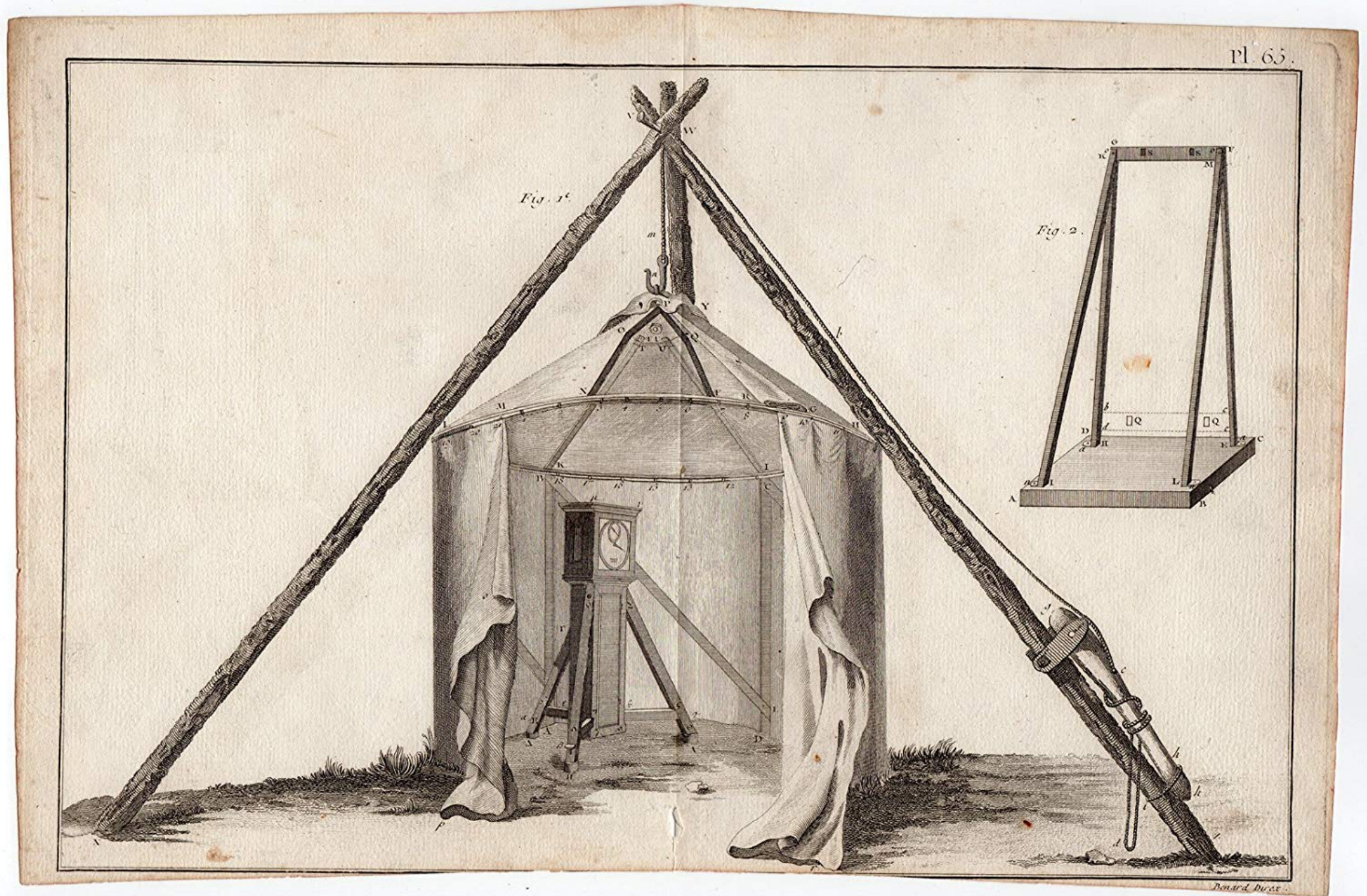
- Requires a telescope (1609)
- Works great on land (starting in 1680's)
- Widely used to make land maps
- Predictable eclipses (speed of light...)



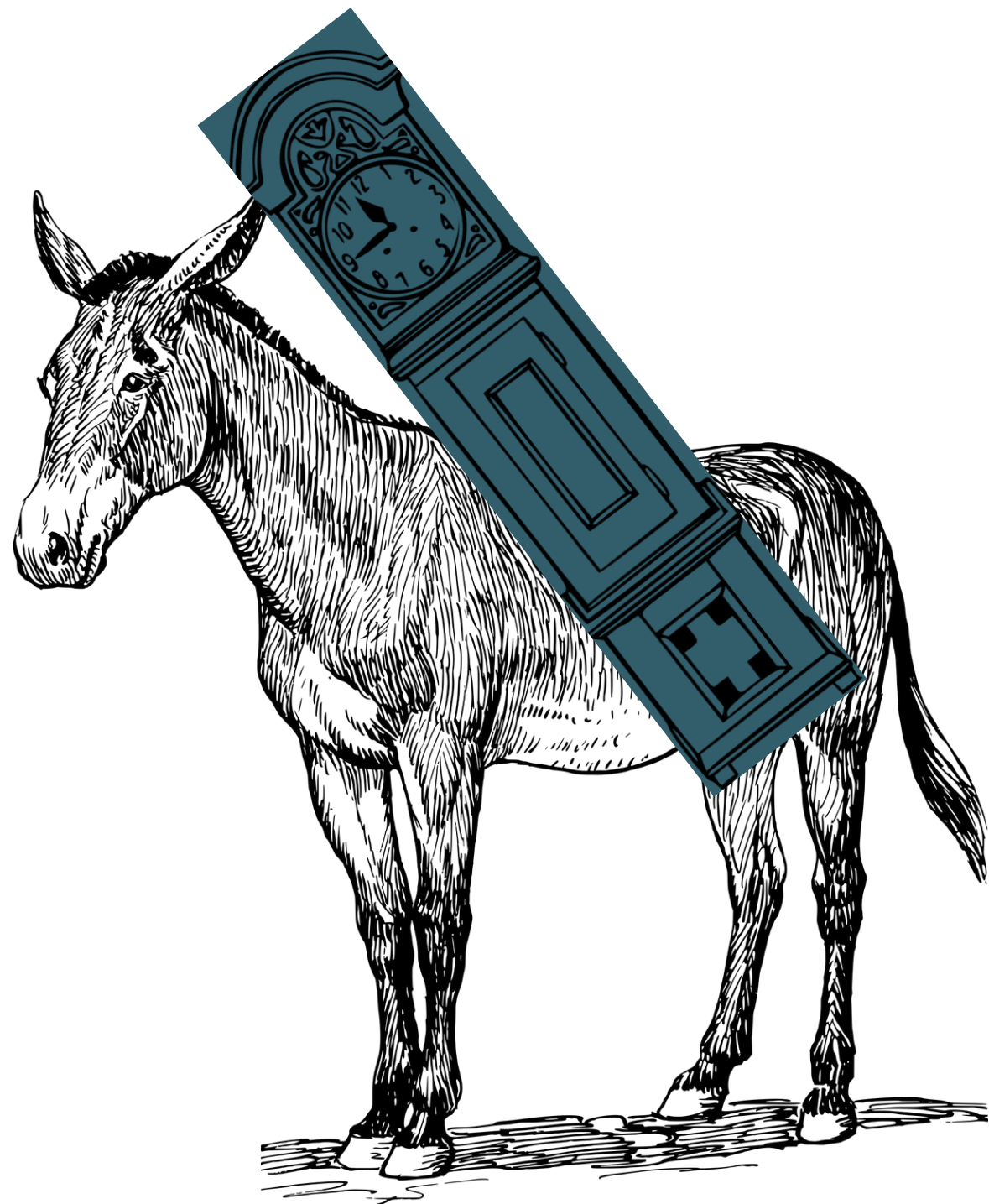




# Cook transit of venus 1778








# Problems of sea

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- Jupiter is not visible all the time
- Can't see the moons on a pitching deck
- Need a simple observation (bright star, etc.), and need to know the time

# Two approaches

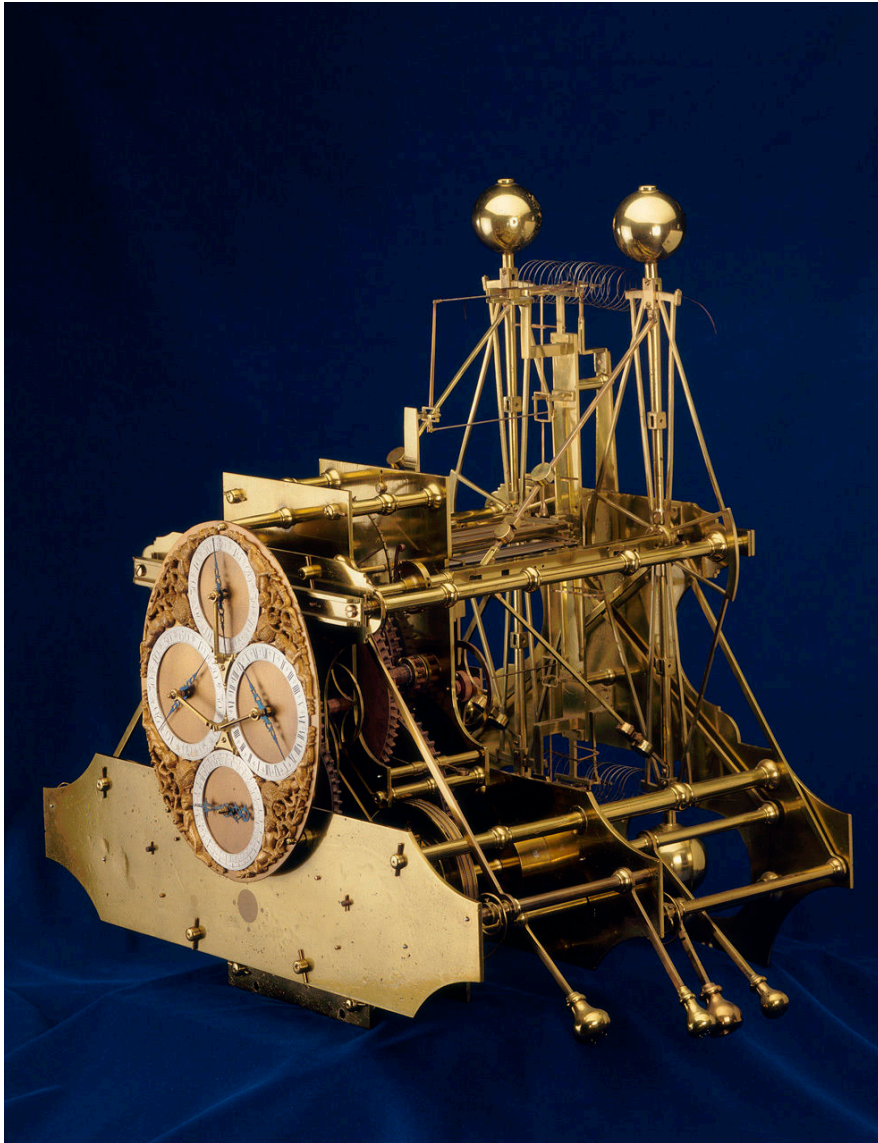
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- Lunar distance to stars
  - Requires calculating in advance where the moon will be 
- A better clock
  - A clock that can accurately keep time on a moving ship

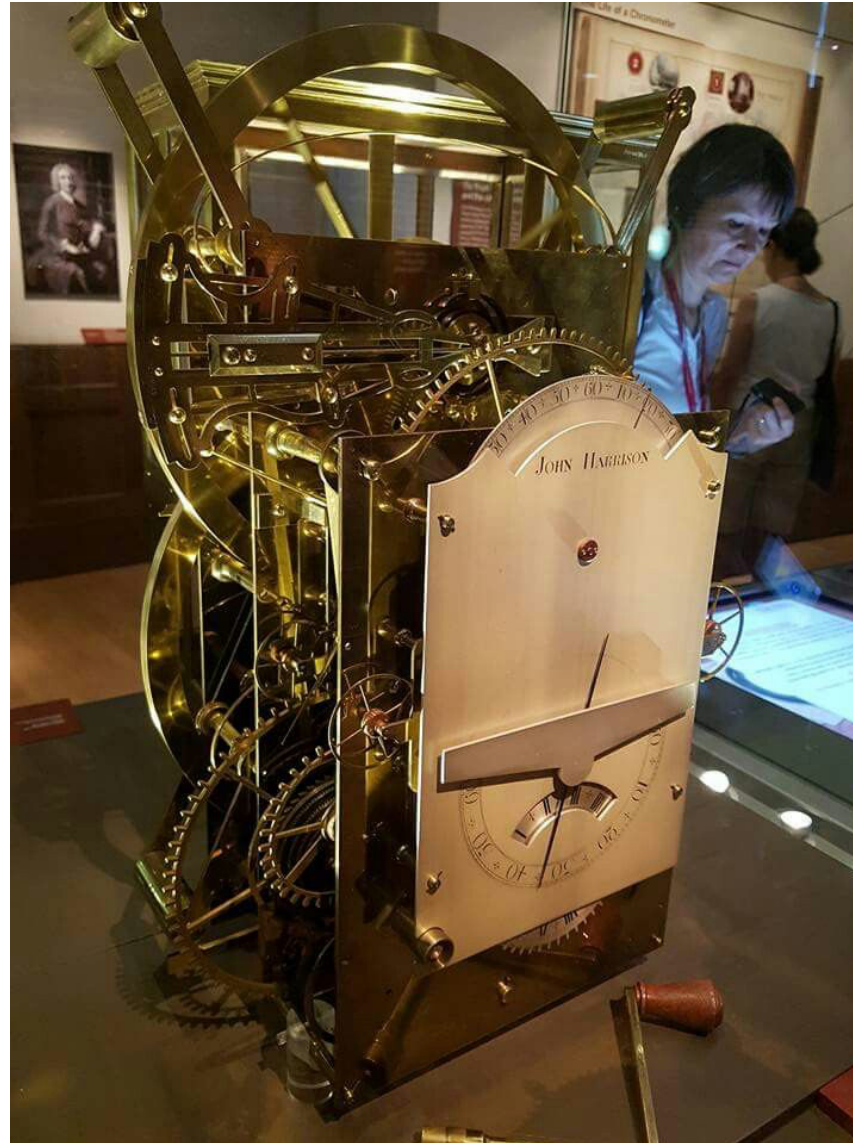


# John Harrison & Longitude

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H1



Arnold chronometer

The full process



Observing stars  
to measure local  
time





# Time ball to tell ships the time

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# Finding local longitude

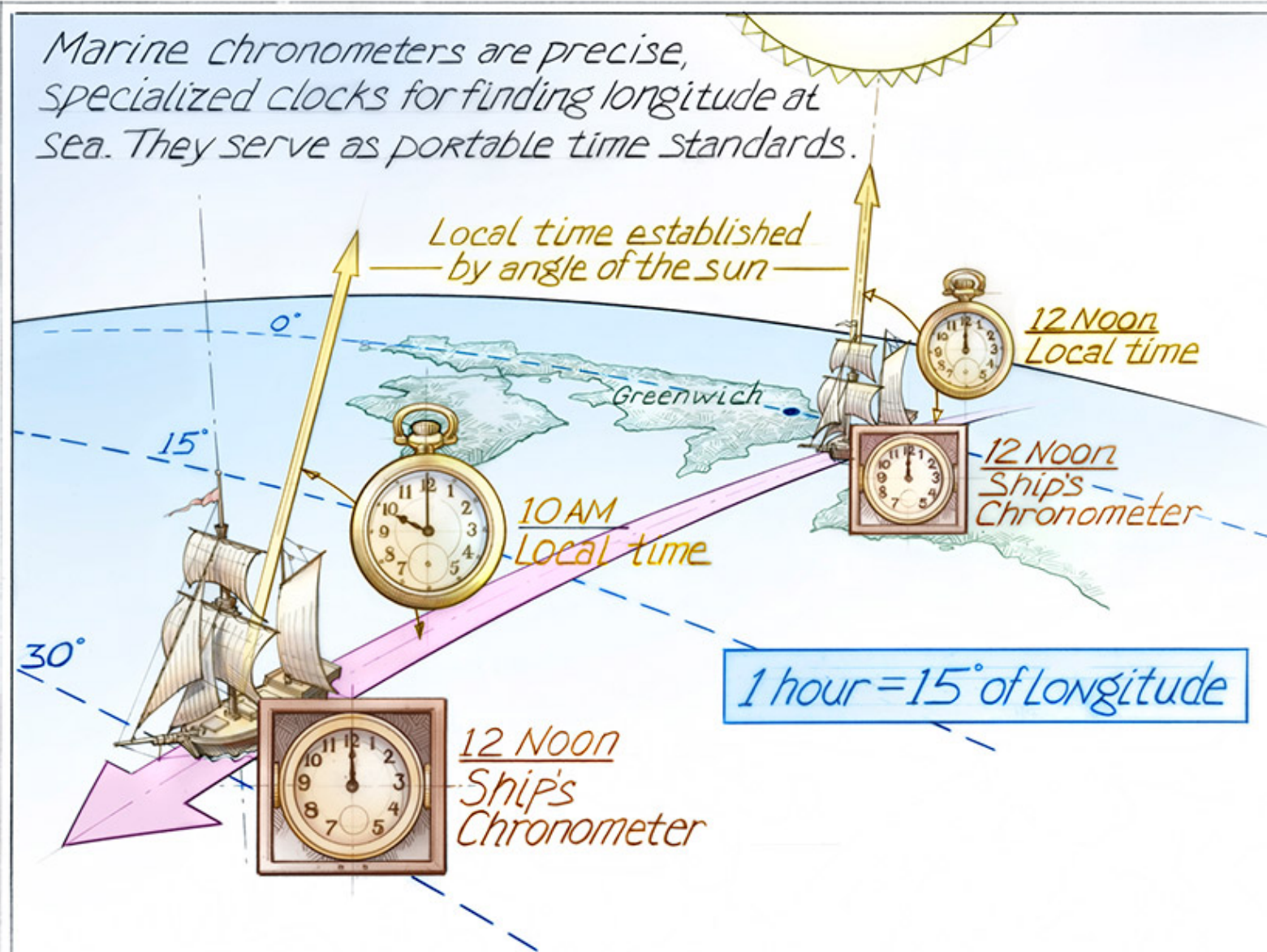
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## USING A MARINE CHRONOMETER

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# Technical state of the art ~1780s

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- Pushed what could be done, invention of caged ball bearings & bimetallic strip
- Arnold, Earnshaw, Emery, Brequet, worked to make chronometers in 'production'
- Expensive but crucial instrumentation

Trains and time zones



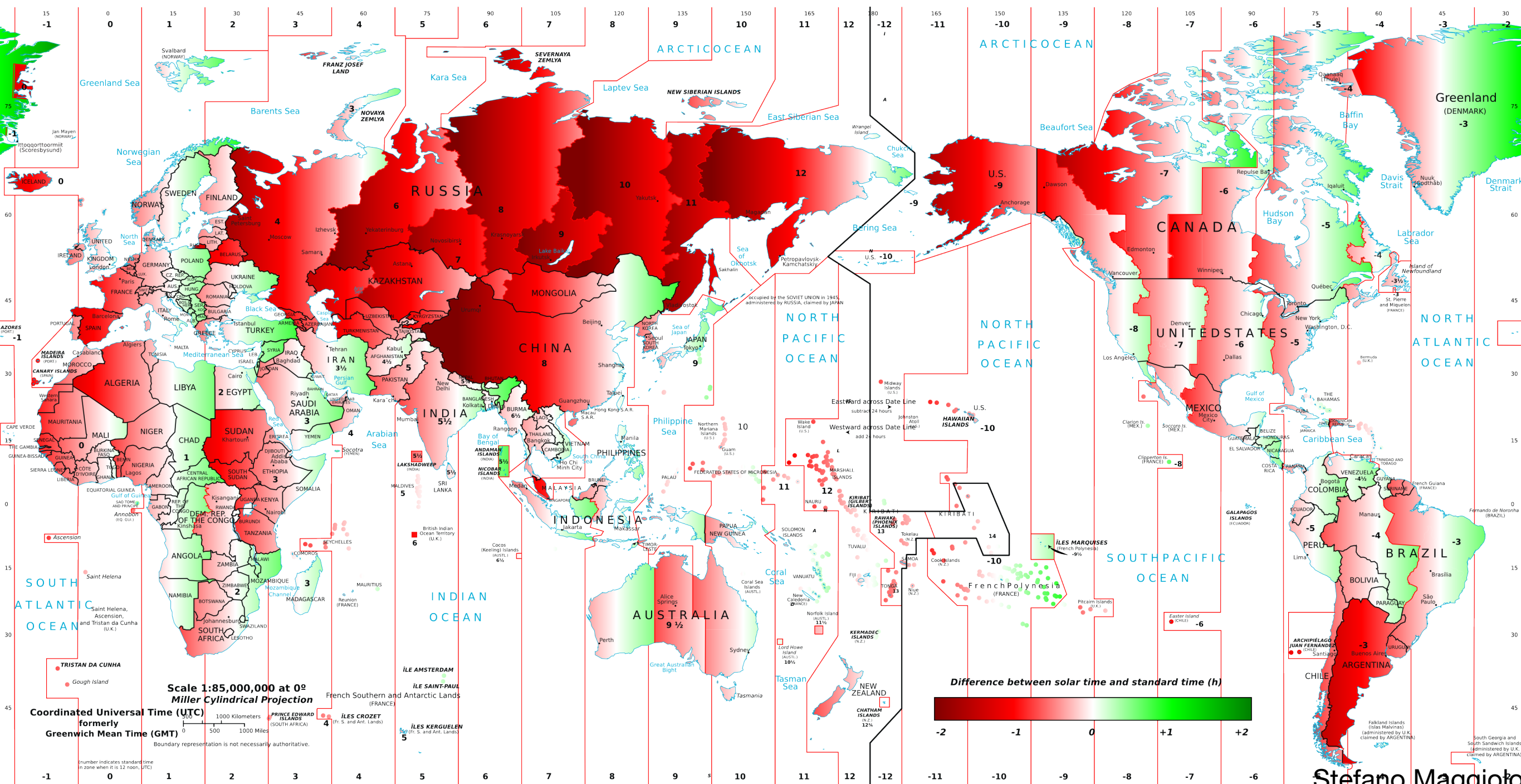
# Train chronometer

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- Trains used time to avoid collisions (!)
- Keeping accurate time became important
- Set up time zones (initially in Canada)
- Transition from local time (stars) being primary to a transferred time being paramount







Stefano Maggiolo



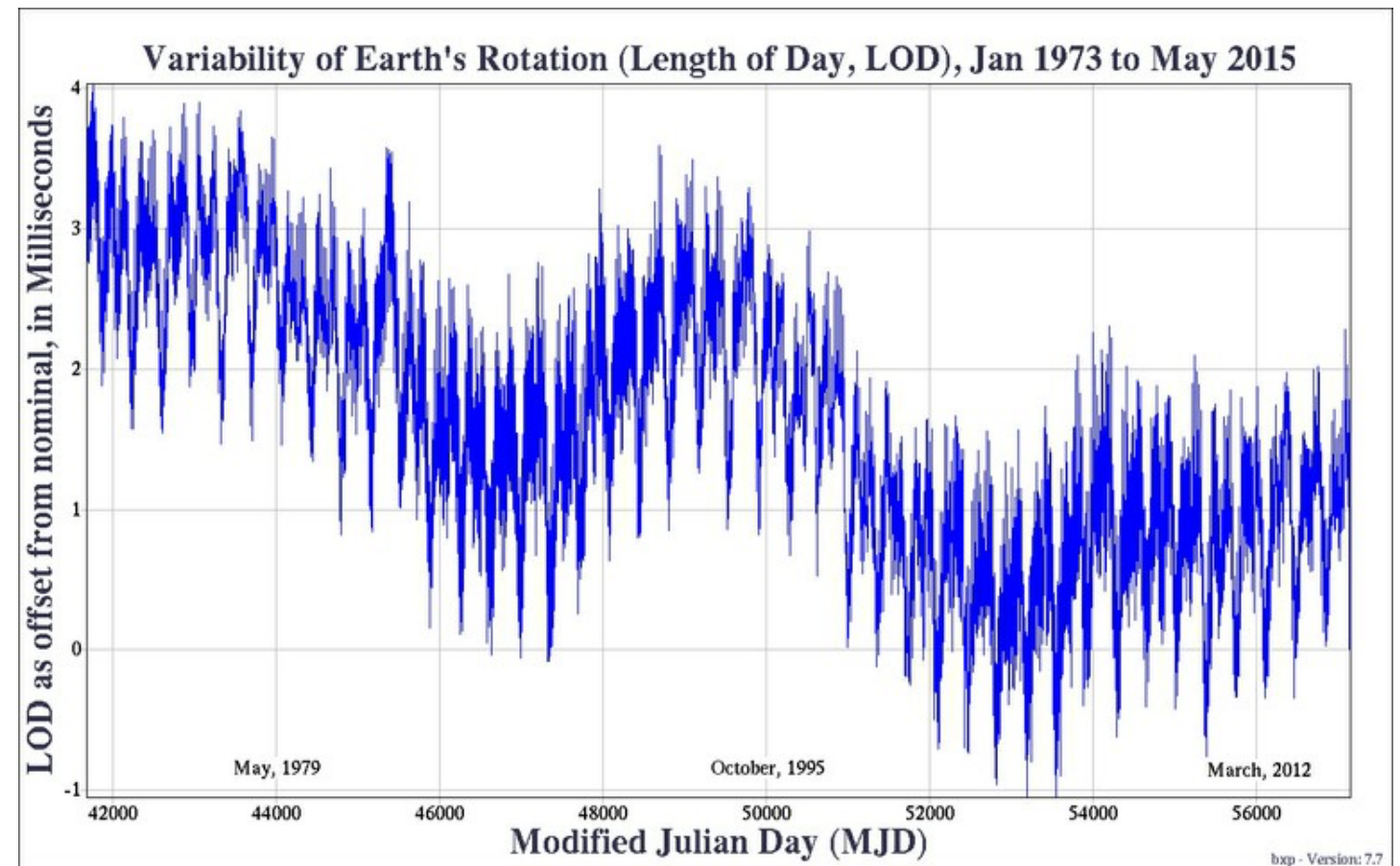
# For your grandparents

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- Time defined by spin of the earth and observations of the stars
- Time at another location can be transmitted. Either by a precision mechanical watch, radio signals, or telegraph/telephone

# US Naval Observatory Earth Rotation and Reference Systems Rapid Service/Prediction Center

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To understand GPS, we need to understand light.  
Next week, what is light, introduction to quantum  
mechanics...