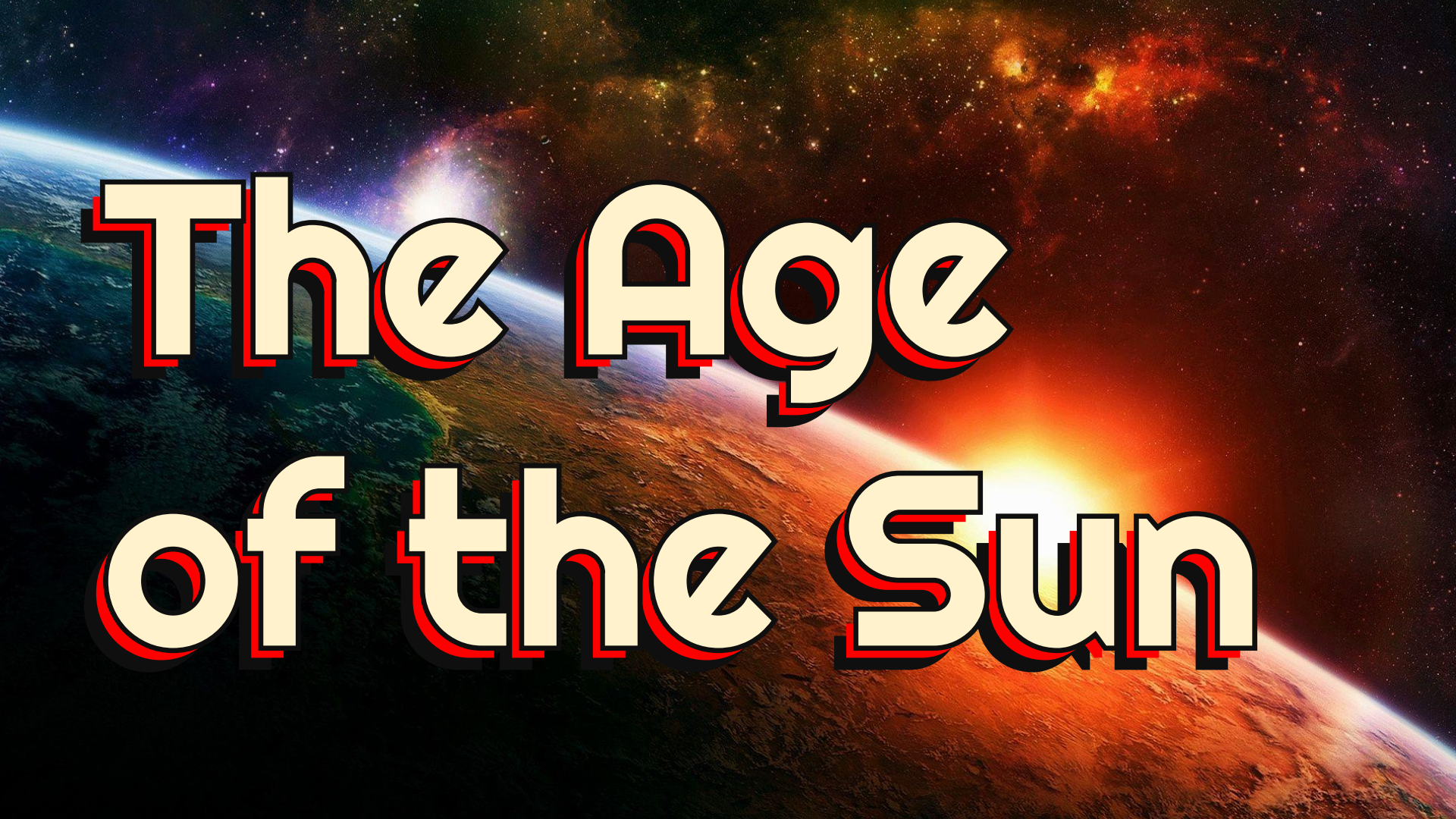
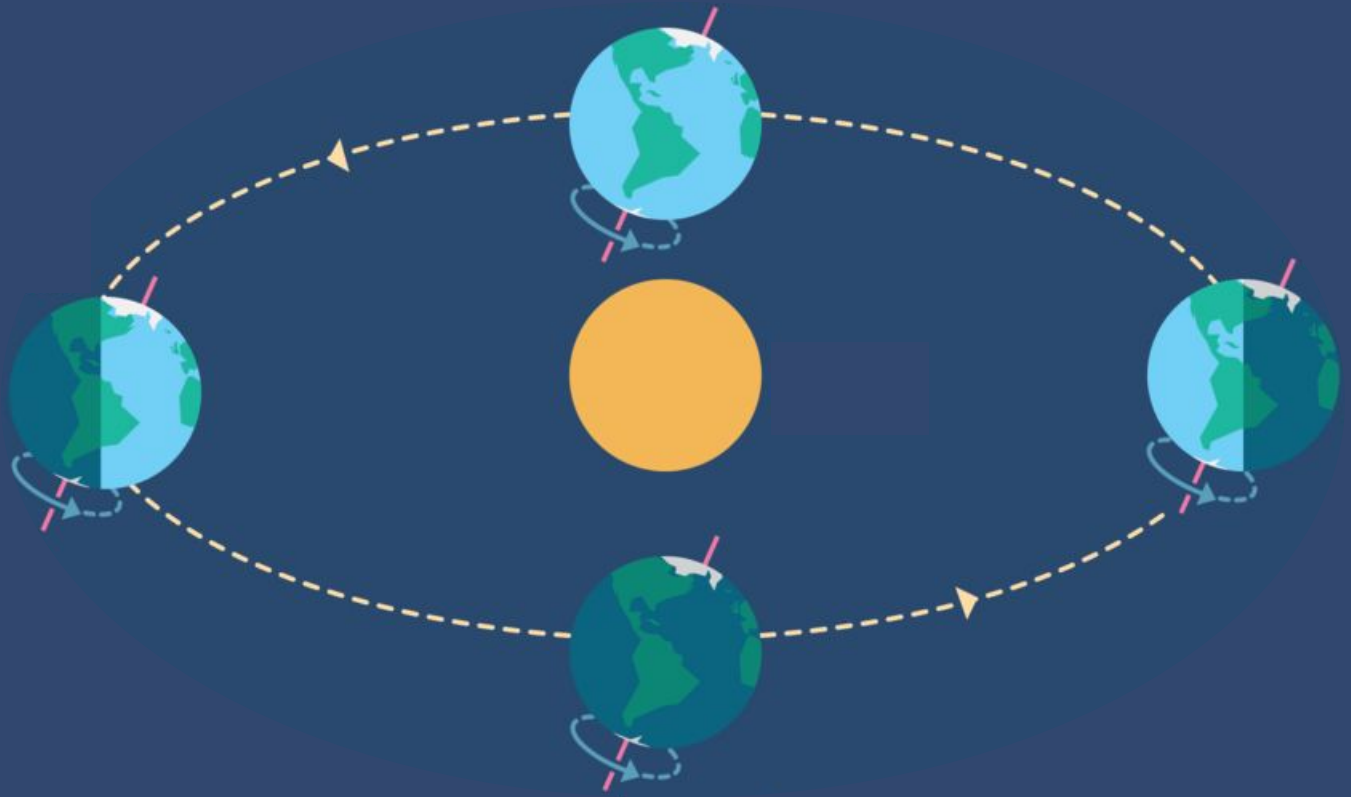
An Almost Complete History of...

Measuring Time

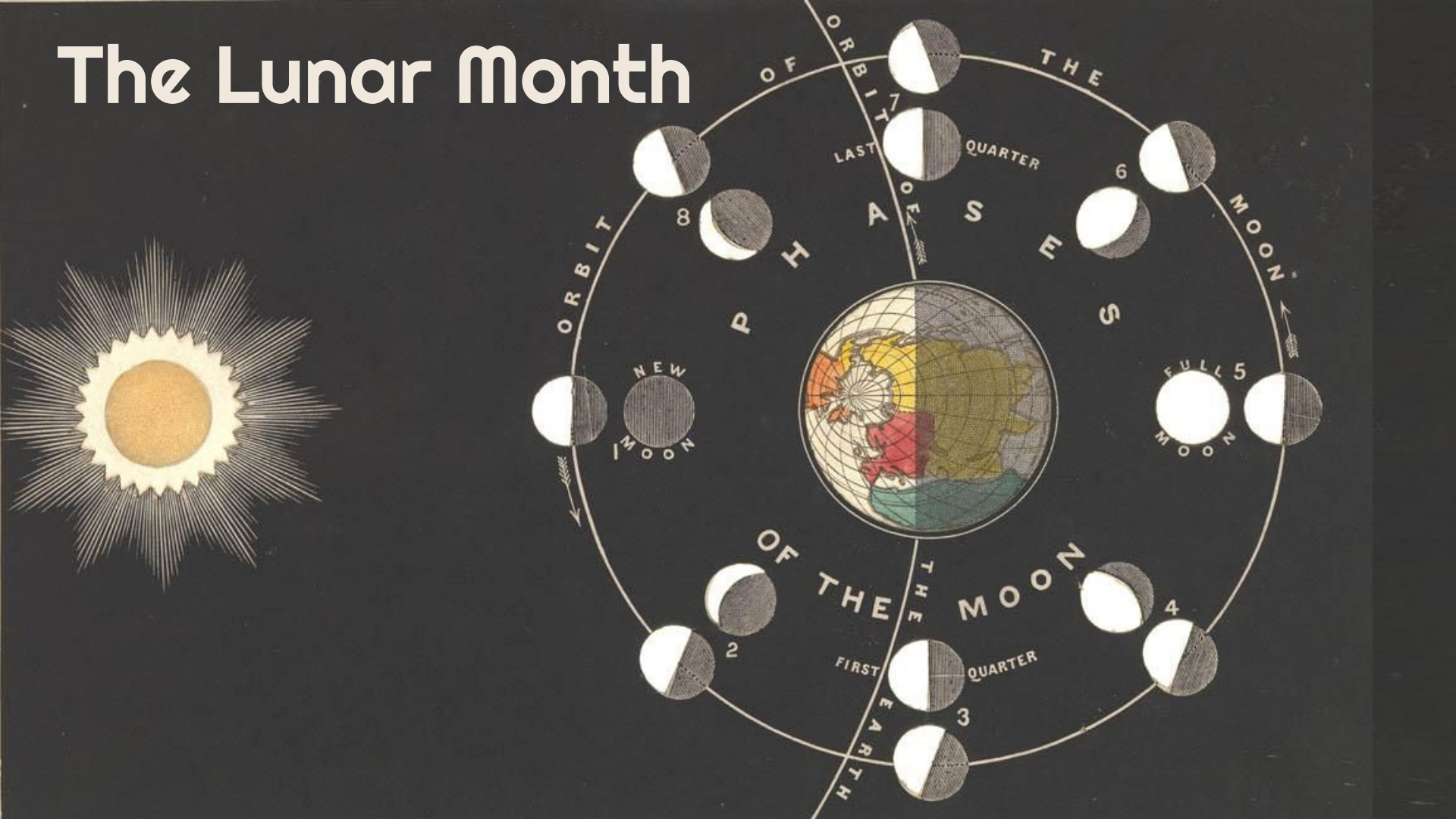
... in 20 Minutes


The Age
of the Sun

The Solar Year

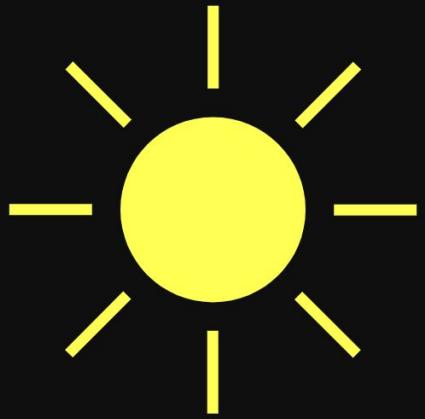


The Lunar Month

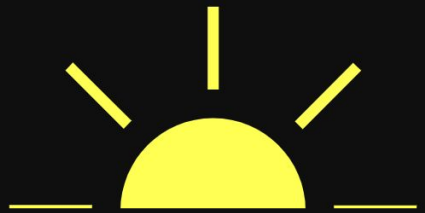


The Three Times of Day

Sunrise



Noon



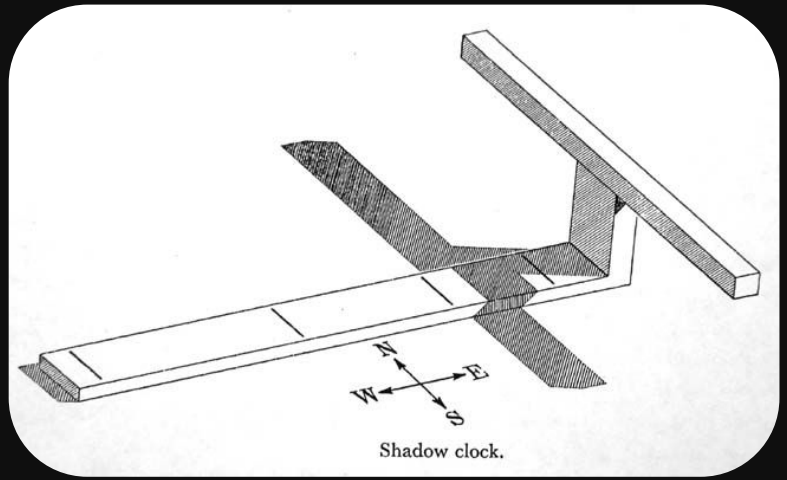
Sunset

3000 BC to 2000 BC

Big Ass Rocks

2300 BC to 500 BC

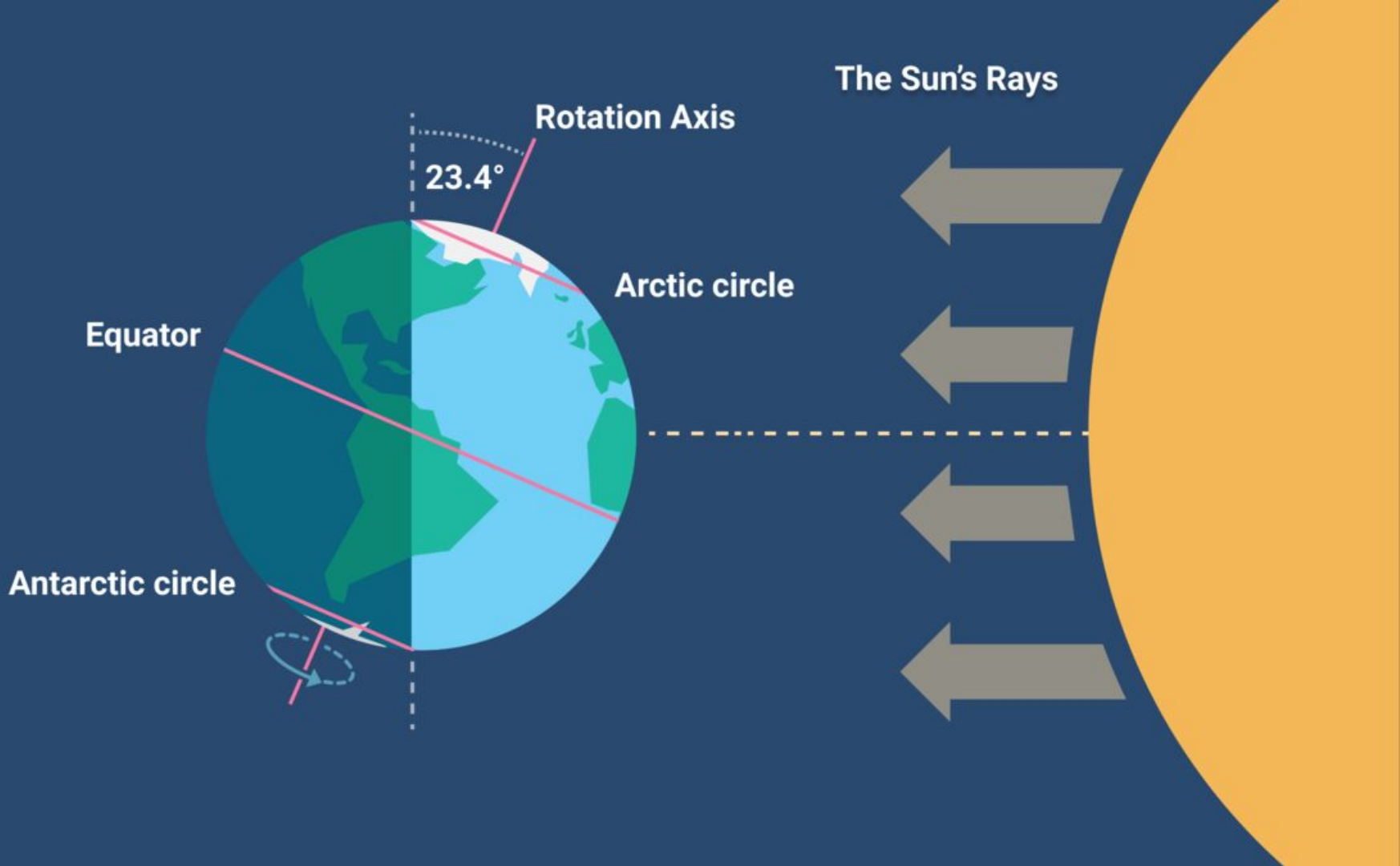
Early Sundials

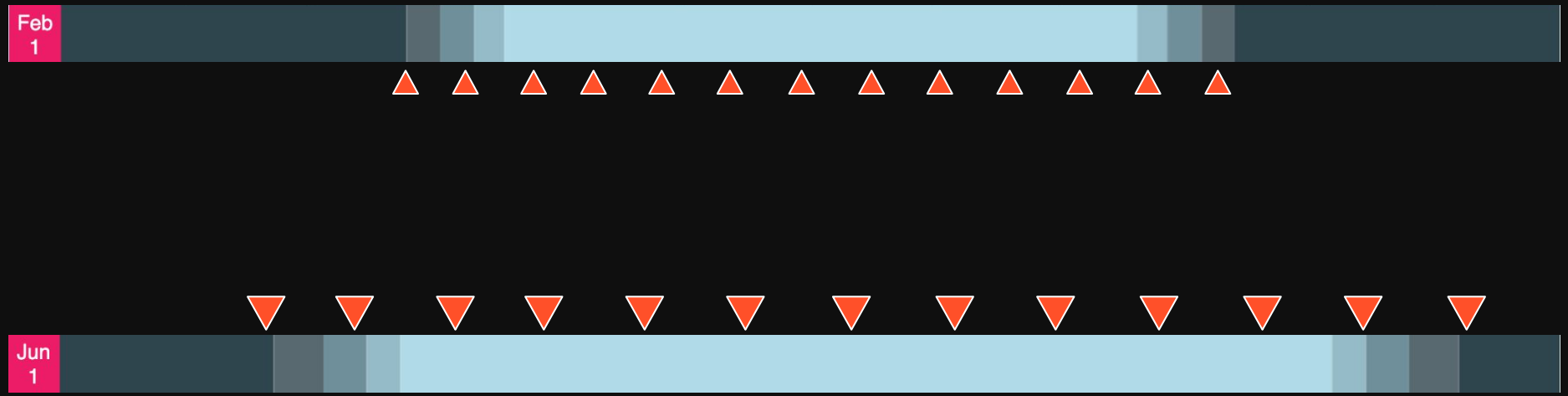


Shadow clock.

Shadow Clocks

Sundials

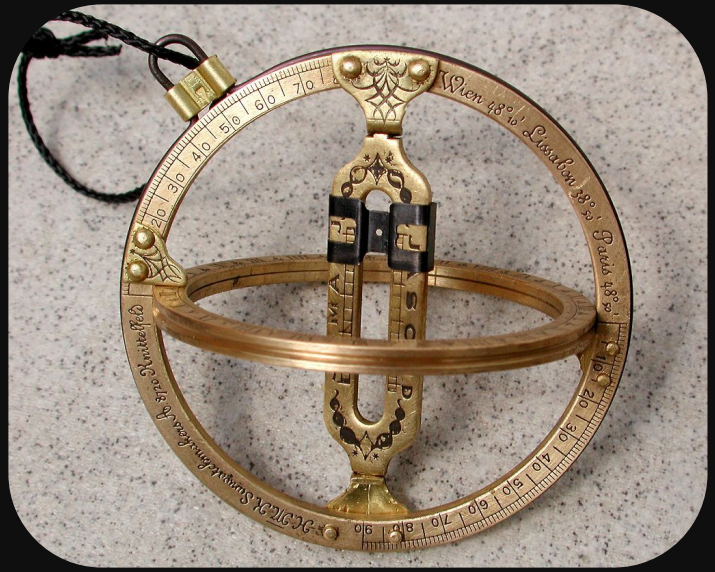

The Sun's Rays
Rotation Axis
23.4°
Arctic circle
Equator
Antarctic circle


Feb
1
Jun
1

2300 BC to 100 BC

Less Bad Sundials

Hemispherical Sundials



Universal Sundials

Pliny The Elder

Tardy

Pliny The ~~Elder~~

Why 12 Hours?


A Quick
Detour in
Math

Decimal Numbers

Decimal Numbers

$$513_{10} = 5\times10^2 + 1\times10 + 3$$

Vigesimal Numbers

Vigesimal Numbers

$$15F_{20} = 1\times20^2 + 5\times20 + F$$

Vigesimal Numbers

“Quatre-vingts” ➡ “Four-Twenties”

Duodecimal Systems

Duodecimal Systems

$$36B_{12} = 3\times12^2 + 6\times12 + B$$

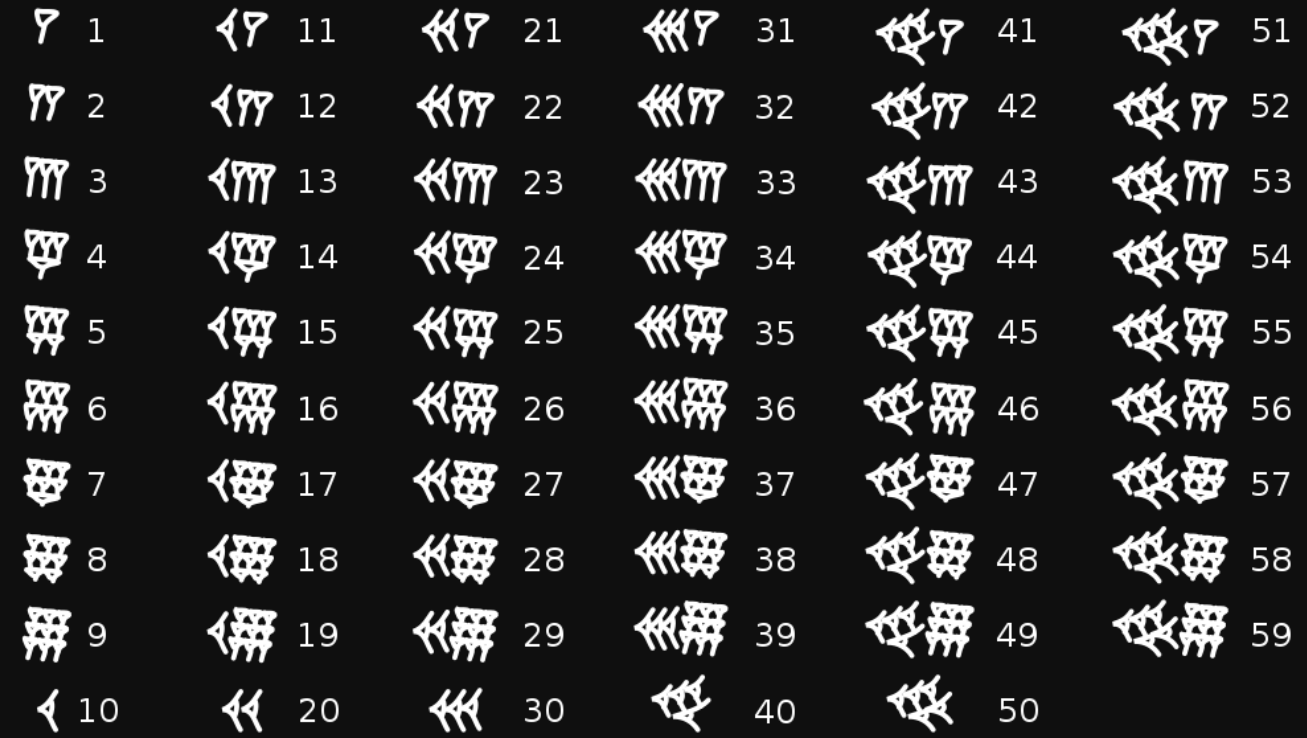
One
Two
Three
Four
Five
Six

Seven
Eight
Nine
Ten
Eleven
Twelve

...
...
Thirteen
Fourteen
Fifteen
Sixteen

$$513_{10} = 15F_{20} = 36B_{12}$$

Babylonian Sexagesimal System



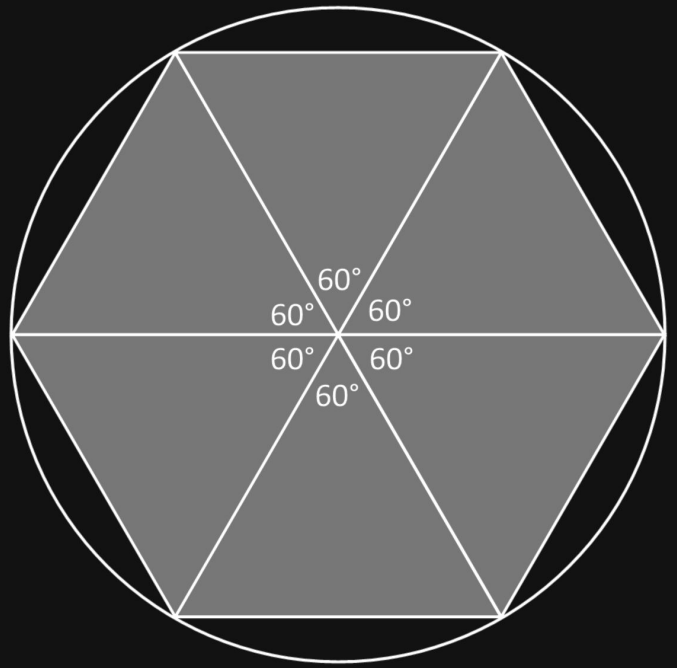
Babylonian Sexagesimal Math

Without Zero

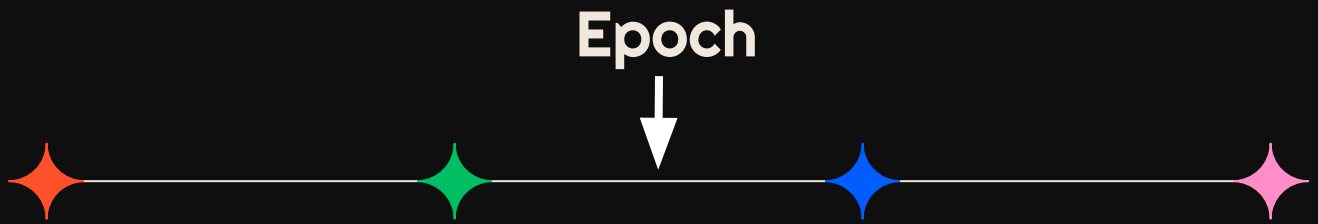
1	10	61	601	3,601	36,001	216,001	2,160,001

With Zero

The Legacy of Sixy



A Quick Aside About Our Calendar and Epochs



800 BC

800 years “Before Christ”

1 BC

1 years “Before Christ”

1 AD

1 years “Anno Domini”
or
“In the year of our Lord”

2022 AD

2022 years “Anno Domini”

800 BCE

800 years “Before Common Era”

1 BCE

1 years “Before Common Era”

1 CE

1 years “Common Era”

2022 CE

2022 years “Common Era”

4 AD

800 BC

1 BC

1 AD

2022 AD

One Year

4 AD

800 BC

1 BC

1 AD

2022 AD

One Year

4 AD

800 BC

1 BC

1 AD

2022 AD

-5 -4 -3 -2 -1 0 1 2 3 4 5

One Year

4 AD

800 BC

1 BC

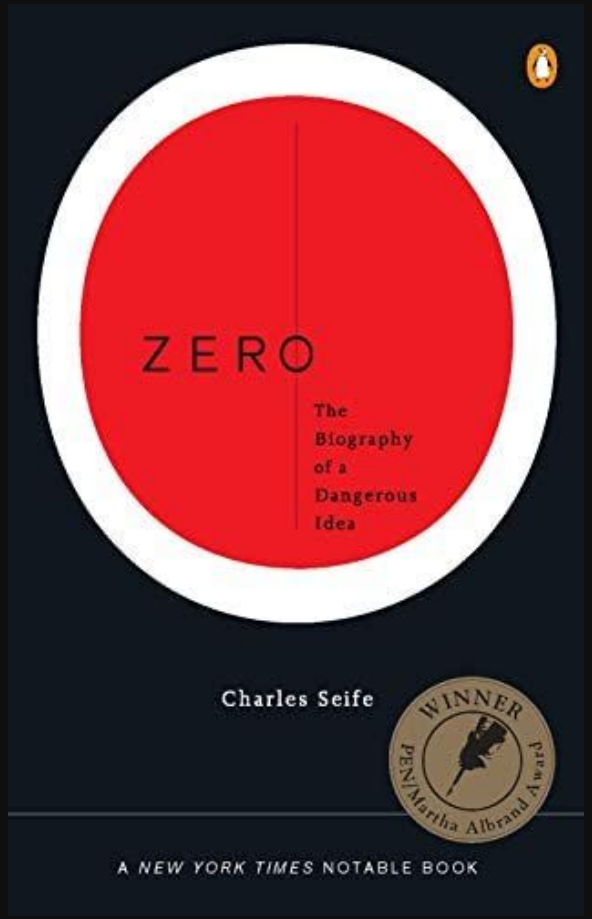
1 AD

2022 AD

2821 years ago

2022 + 800 - 1

-5 -4 -3 -2 -1 0 1 2 3 4 5


ZERO
The Biography of a Dangerous Idea
Charles Seife
WINNER
PEN/Martha Albrand Award
A NEW YORK TIMES NOTABLE BOOK


Night Clocks

Accurate depiction of a night-shift worker in 3500 BC

Water Clocks

1400 BC

Incense Clocks

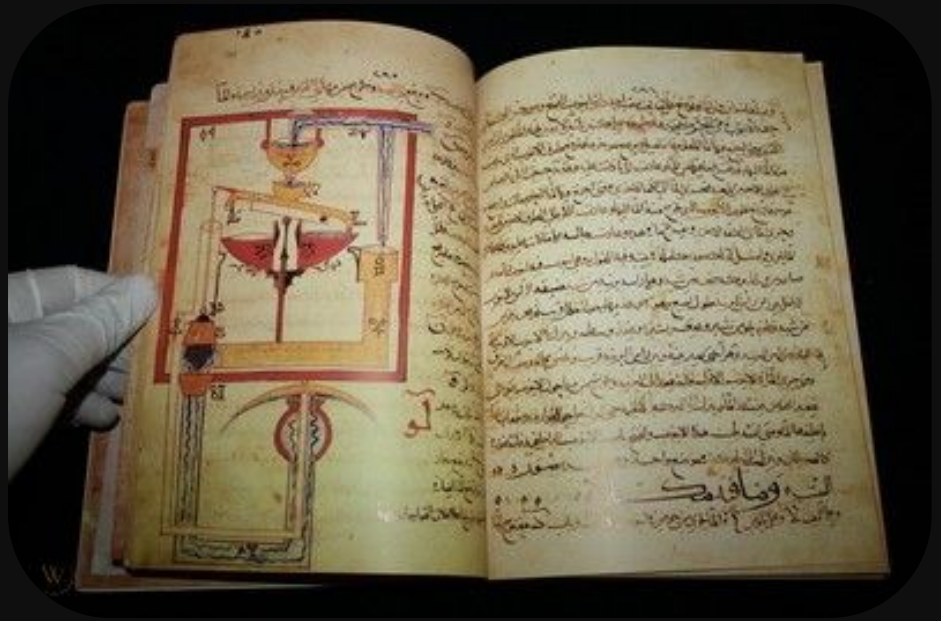
600 AD

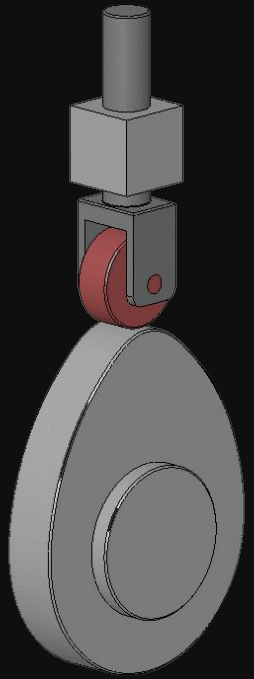
Sandglasses

800 AD

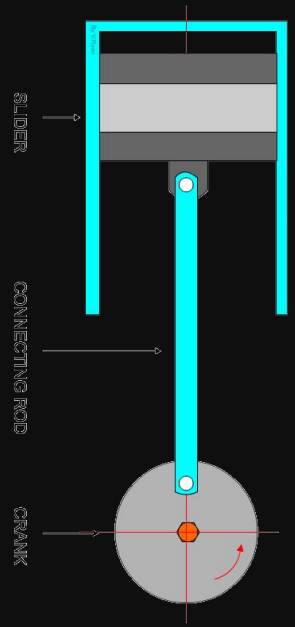
1136-1206 AD

Ismail al-Jazari

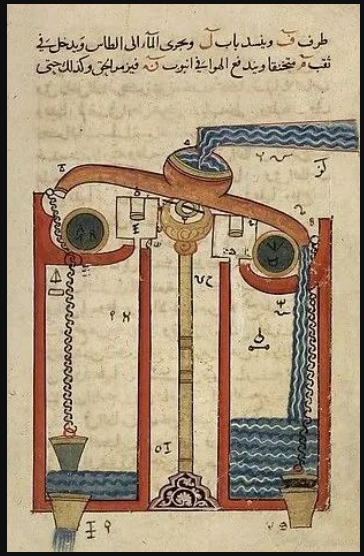




Cams

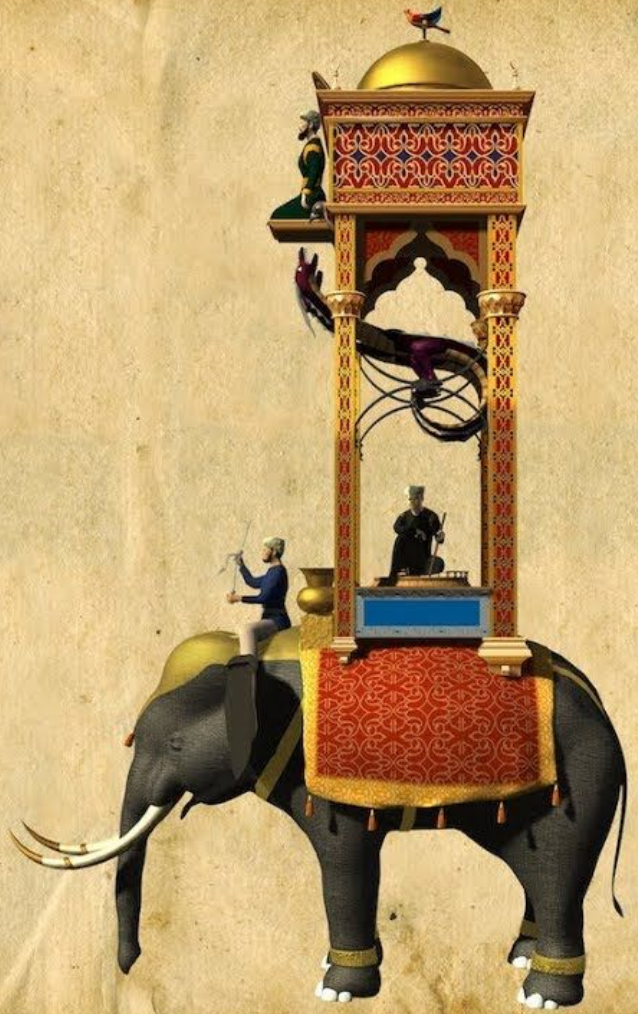


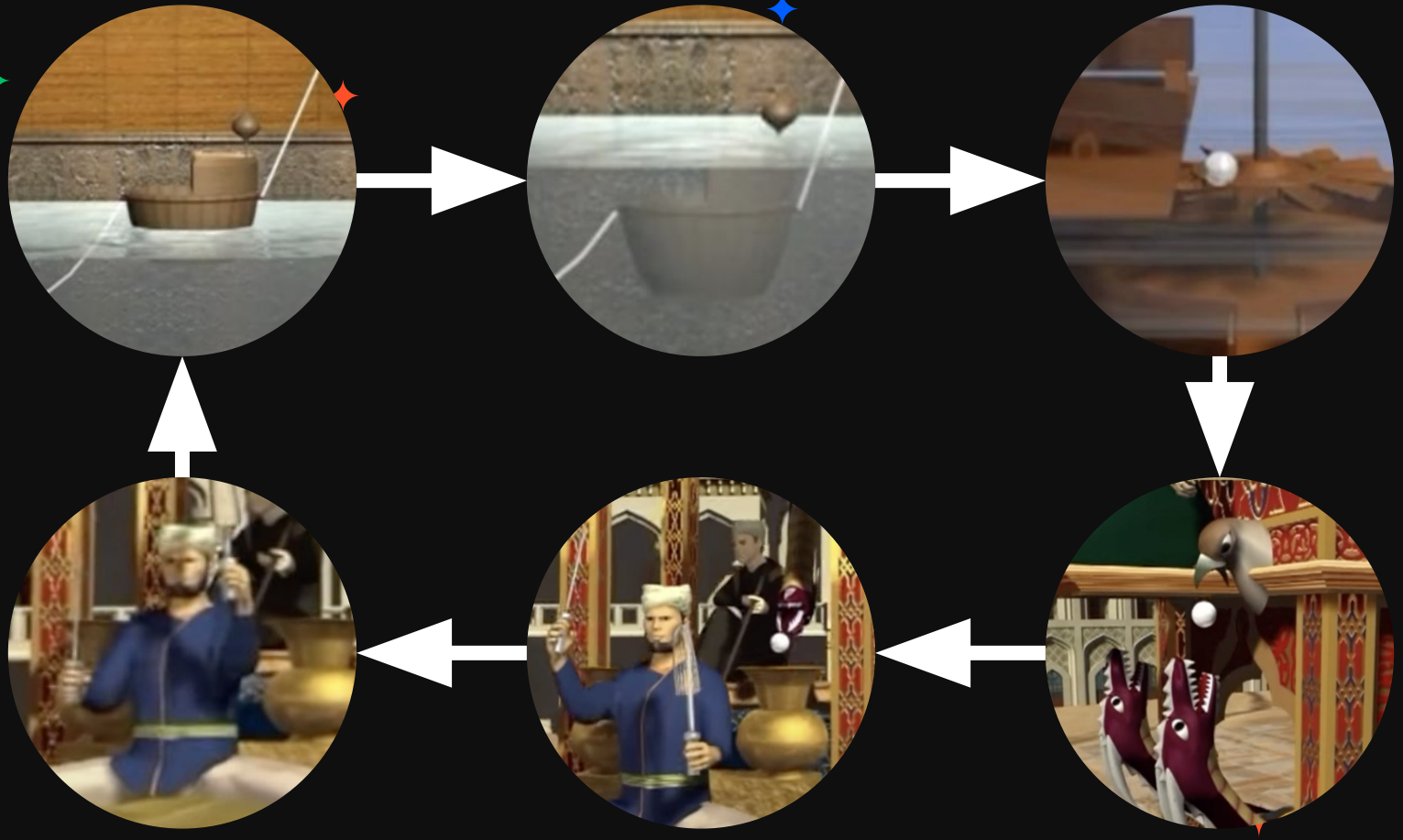
Crankshafts



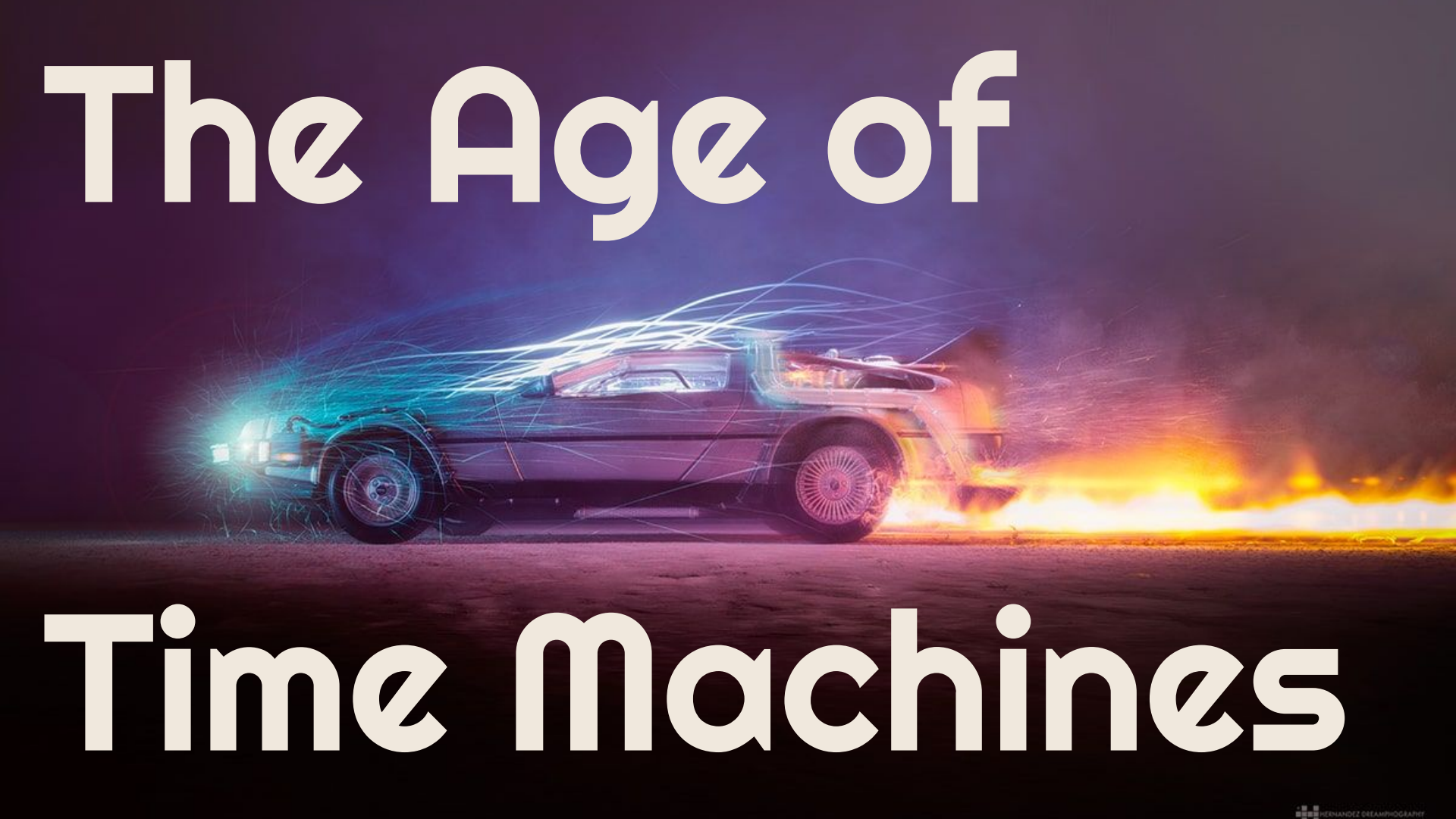
Water

The Elephant Clock





The Age of Time Machines



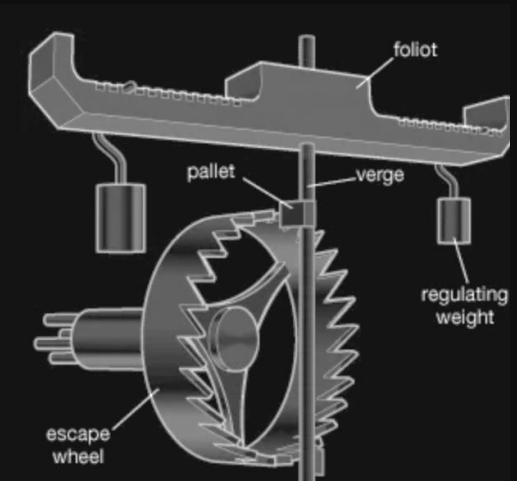

Of The
Clock

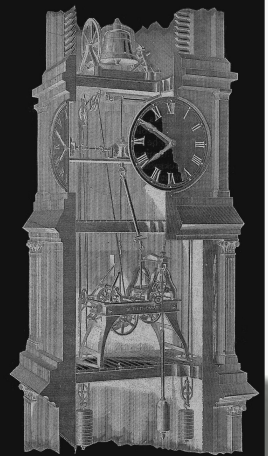

O’Clock

1300-ish AD

Verge and Foliot Escapements

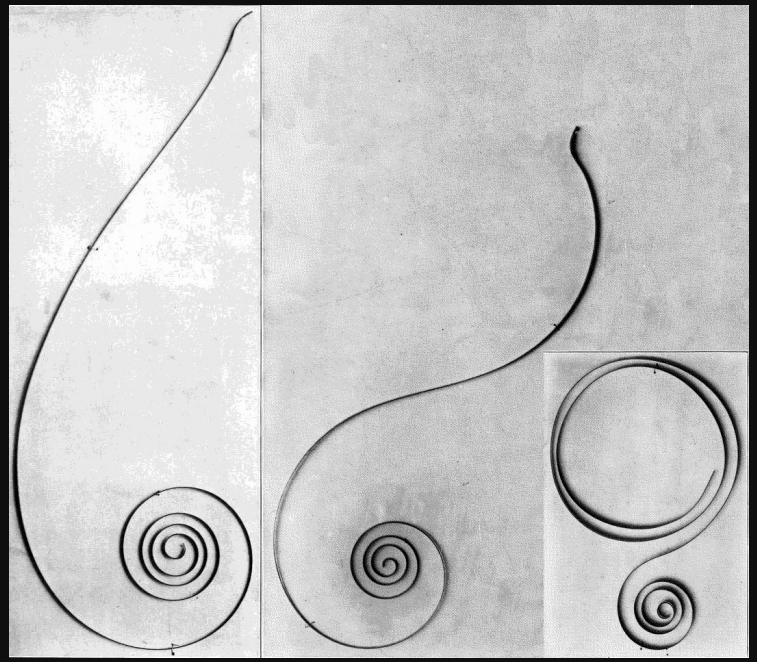
- First practical escapement
- Primarily used in Tower Clocks
- Originally powered bells, not faces

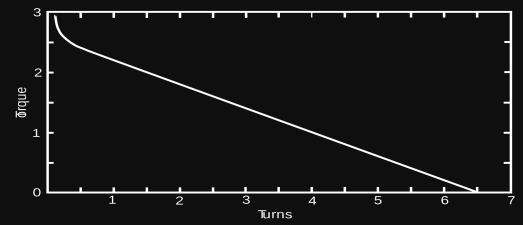


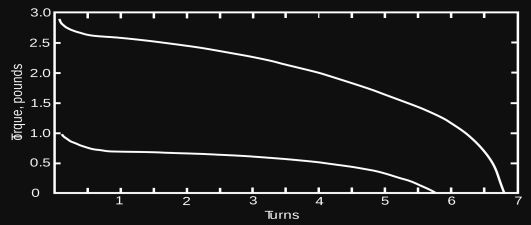


1511 AD
Mainsprings

- **Clocks become pocketable** (1600 AD)
- Not disrupted by gravity
- Improved by hardened steel
- Surprisingly dangerous to clock makers
- Biggest problem is managing the power curve

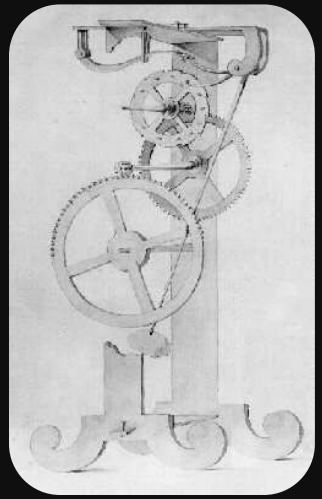


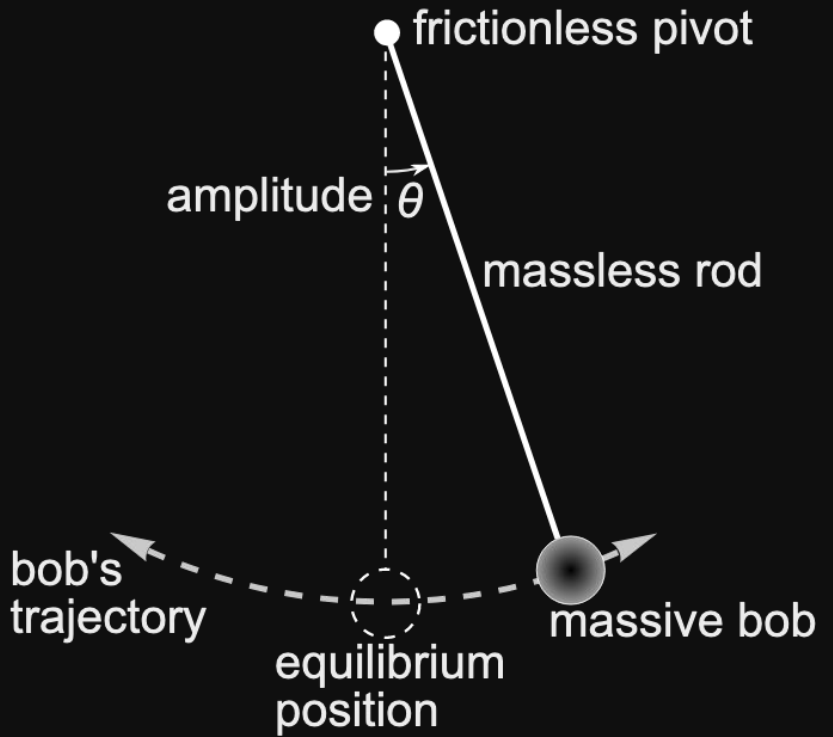




1582 AD
Pendulums

- Galileo notes consistency of a pendulum's period in 1583 AD
- First "Harmonic Oscillator" in clocks

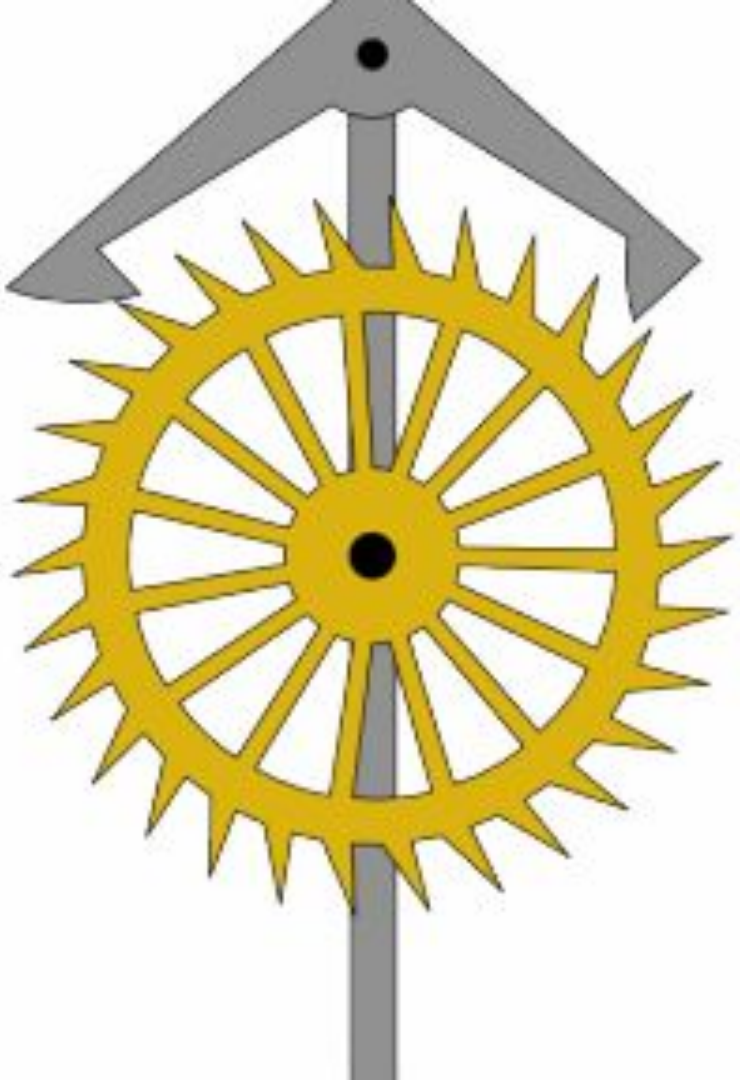




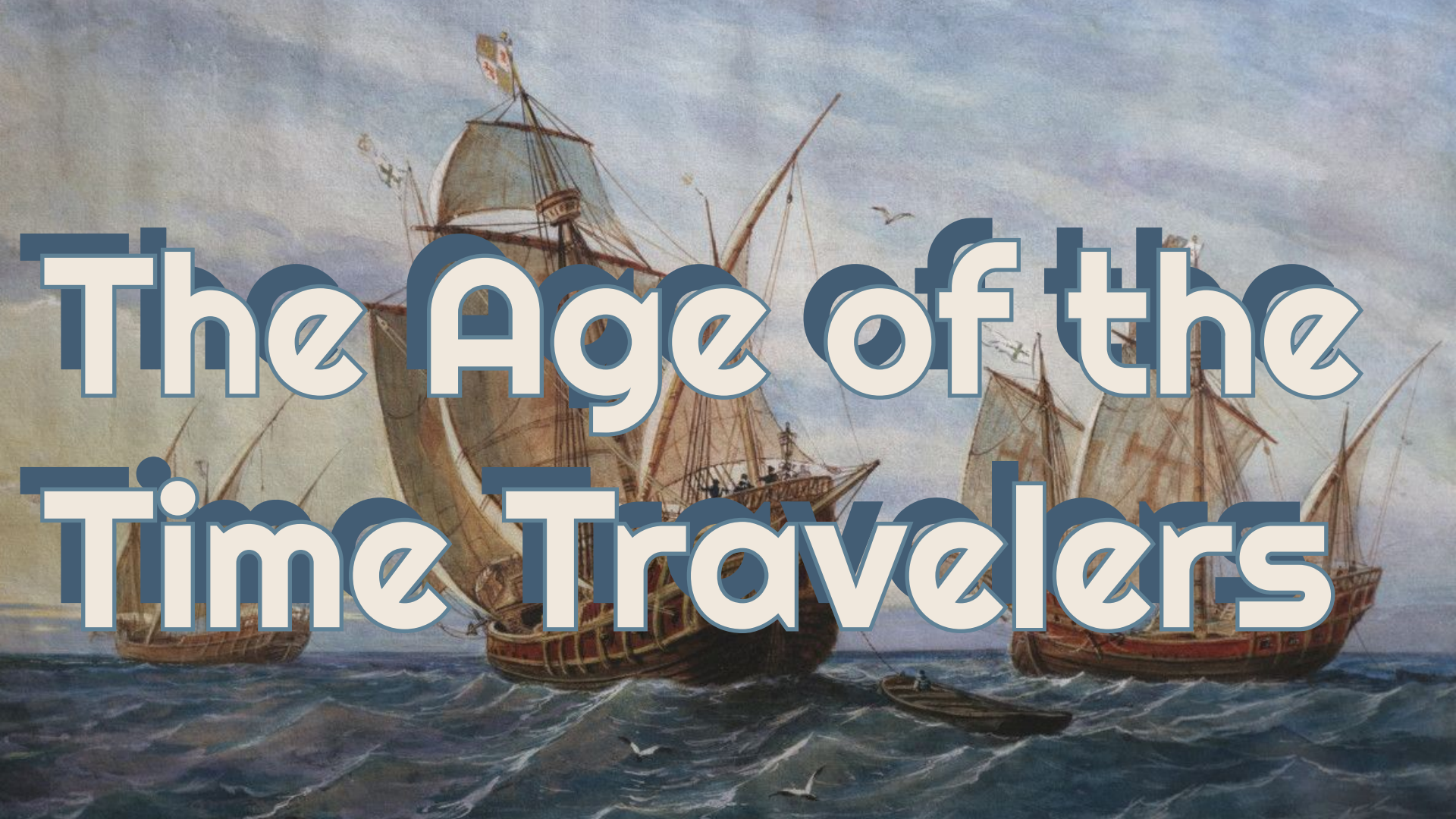
1673-ish AD

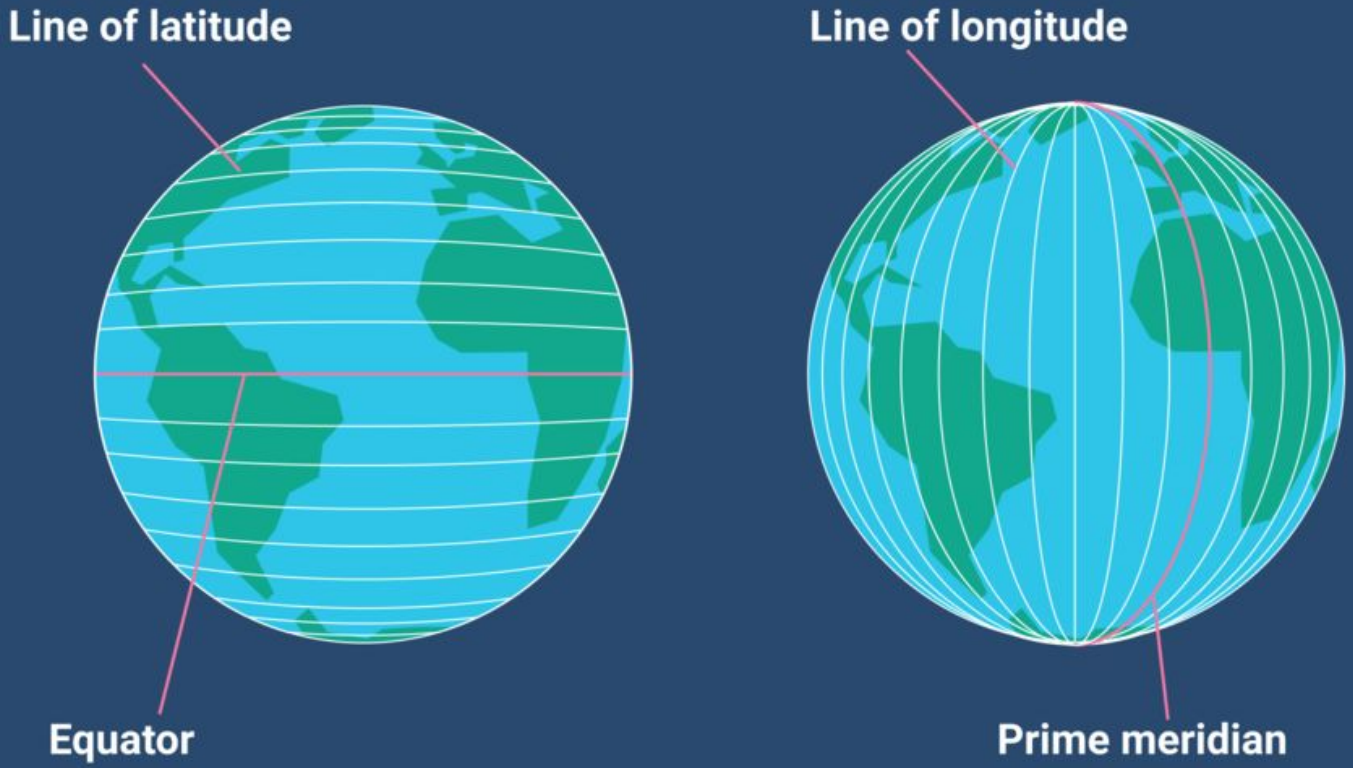
Recoil Anchor Escapements

- Not “anchored” just looks like “an anchor” ⚓
- Used to regulate a pendulum
- “Deadbeat” is an improvement by mathematician Richard Towneley and clockmaker George Graham in 1715
- By 1750s, accurate within 10 seconds per day

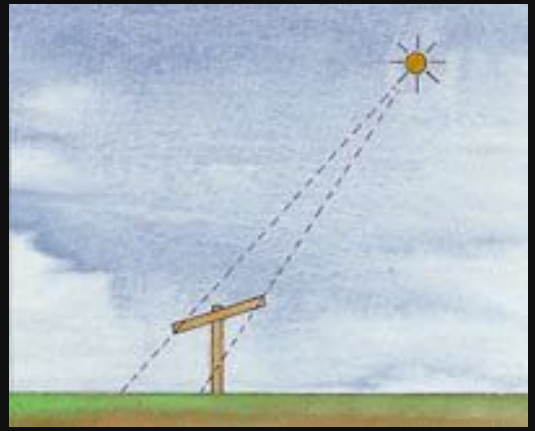


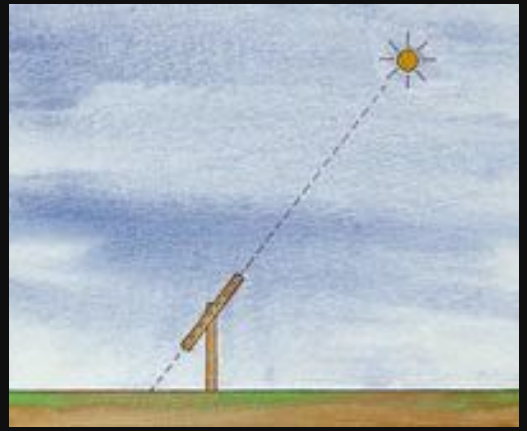

Clocks
Civilization
Sundials

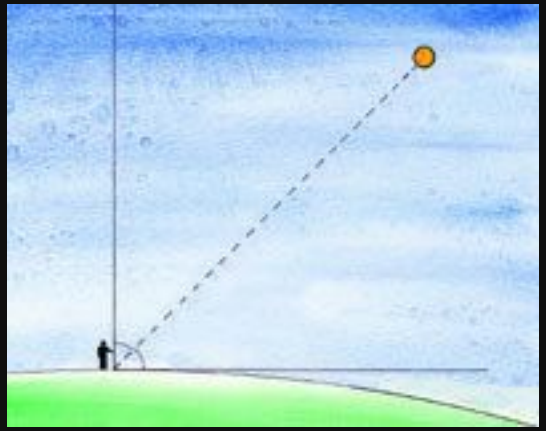

The Age of the
Time Travelers


Line of latitude
Equator
Line of longitude
Prime meridian

Determining Latitude







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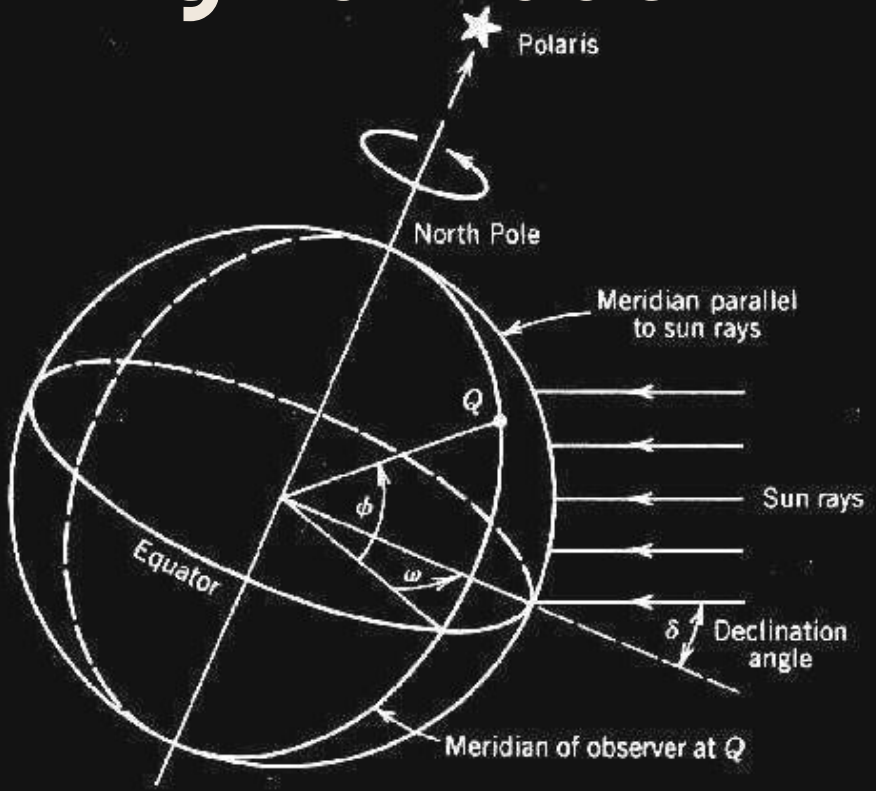
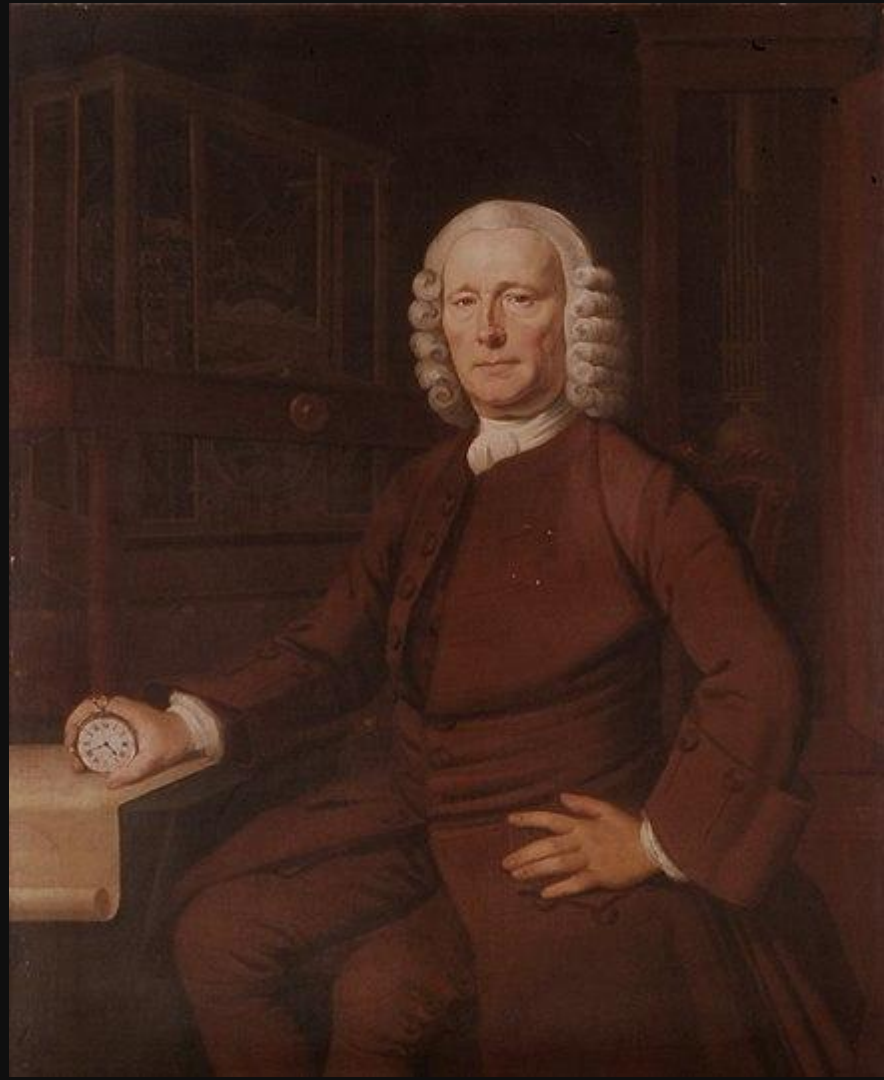


1759 AD

John Harrison

Inventor of the Good Enough Marine Chronometer

- In 1714, Queen Anne offered 20,000 pounds
- Traveling from Britain to Jamaica and back his clock only lost 5 seconds




Arctic Circle
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Moldova
Romania
Monaco
Andorra
Vatican City
Italy
Bulgaria
Georgia
Armenia
Azerbaijan
Turkmenistan
Kazakhstan
Uzbekistan
Kyrgyzstan
Tajikistan
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Spain
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Turkey
Malta
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Syria
Iraq
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Kuwait
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Pakistan
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Oman
Yemen
Western Sahara
Mauritania
Mali
Niger
Chad
Sudan
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Djibouti
Ethiopia
Somalia
Maldives
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Belize
Guatemala
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Guinea
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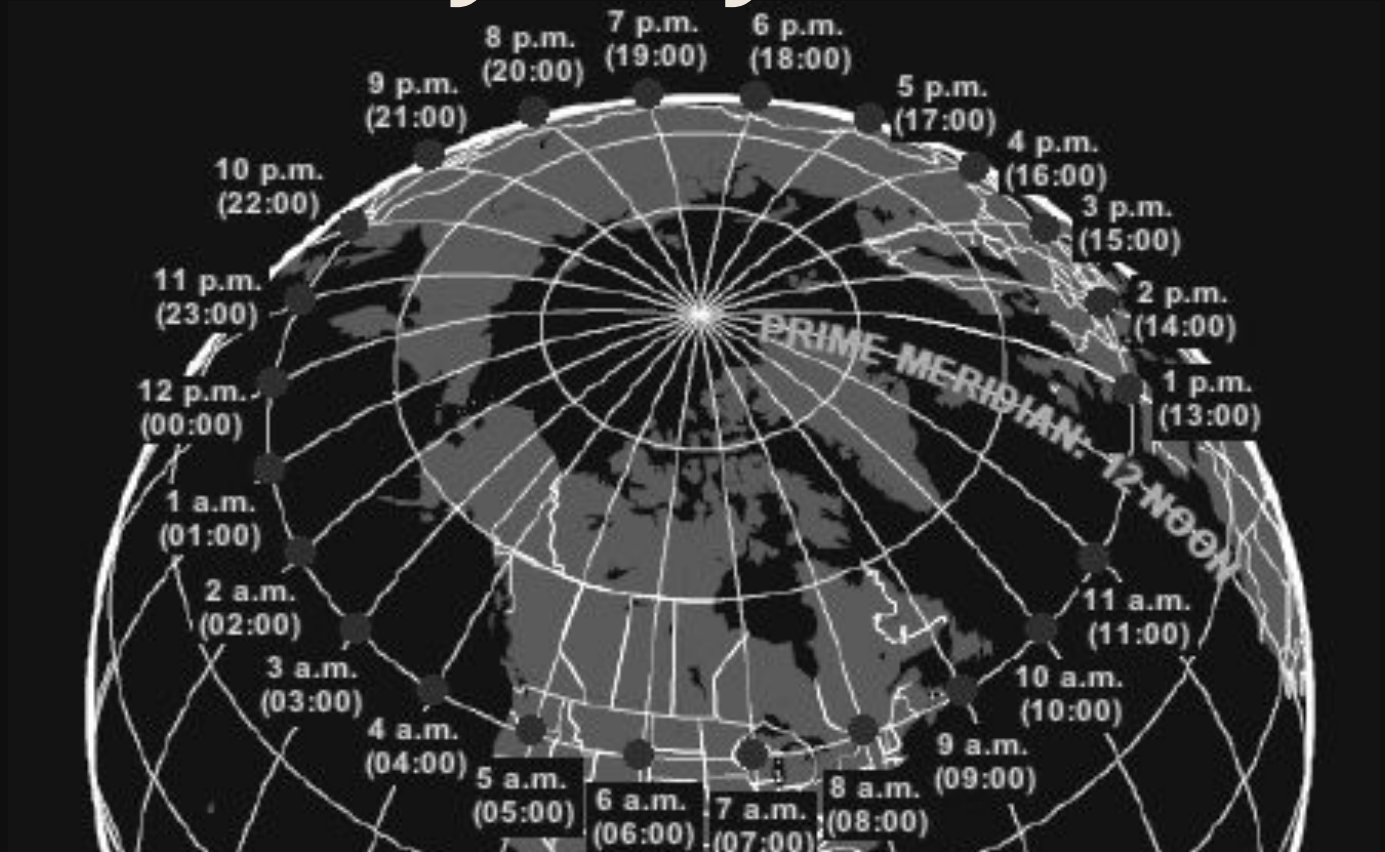
Angola

Determining Longitude




9 AM
Noon
Arctic Circle
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Sierra Leone
Liberia
Côte d'Ivoire
United States of America
Mexico
Guatemala
Belize
Honduras
El Salvador
Nicaragua
Costa Rica
Panama
Colombia
Venezuela
Ecuador
Peru
Brazil
Suriname
French Guiana (Fr.)
Guyana
Trinidad & Tobago
Barbados
Grenada
St. Lucia
Dominica
Antigua & Barbuda
St. Kitts
Puerto Rico
Dominican Rep.
Haiti
Cuba
The Bahamas
Jamaica
NORTH ATLANTIC OCEAN
INDIAN OCEAN


Noon
24 hours in a day
360 degrees of longitude
4 minutes = 1 degree


Problems
with
Time
Traveling

- Great Britain 10 degrees of longitude wide
- 10 degrees = 20 minutes

If I want to deliveries from one side of the coast from the other, which clock should I use?

Which clock should a train schedule use?

Greenwich Mean Time

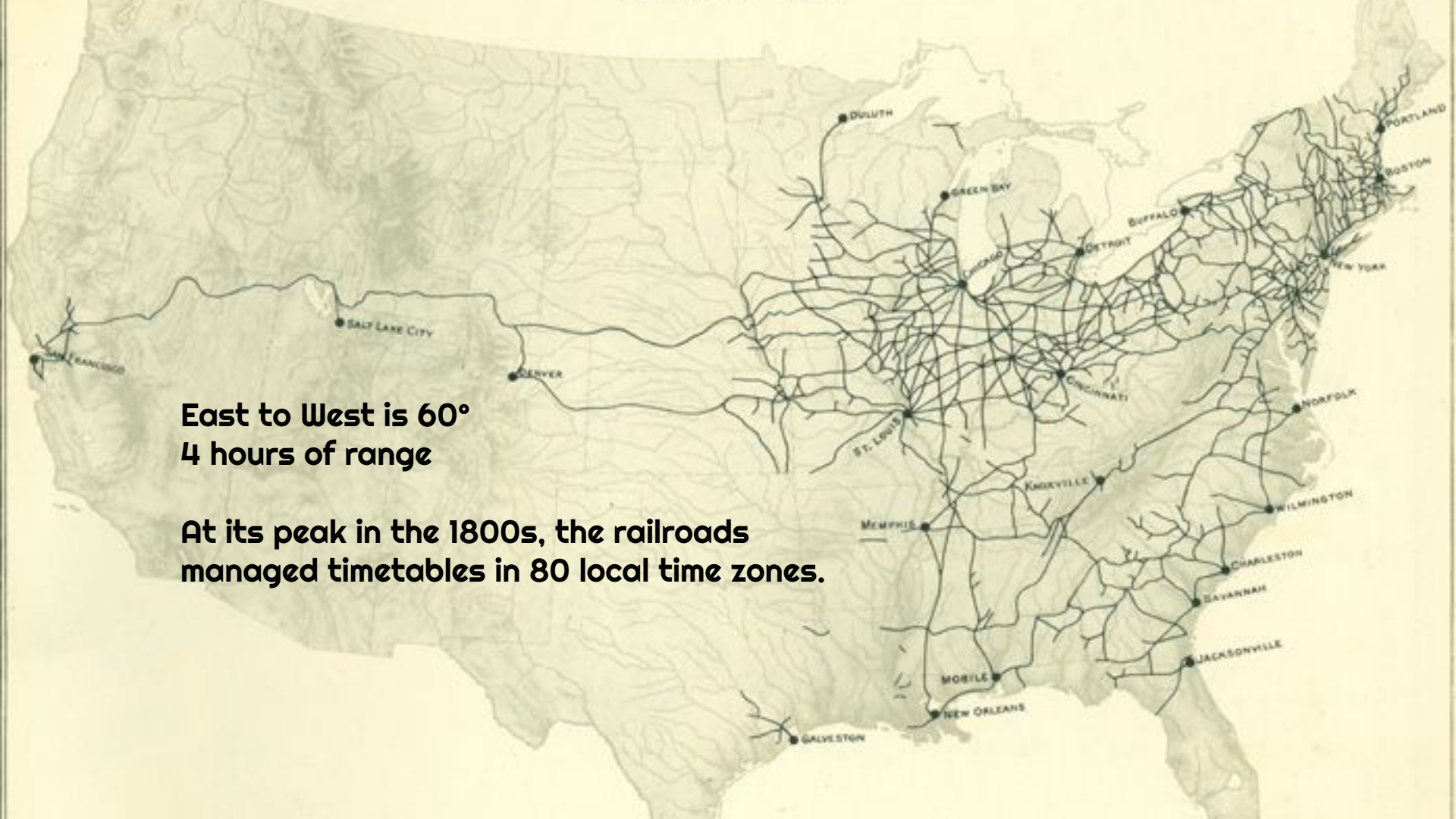
1848 - Railroads standardized on GMT

1852 - Time is transmitted via telegraph lines

1855 - All public clocks showed GMT

For a fee private subscribers could also be hooked up to receive the time signal

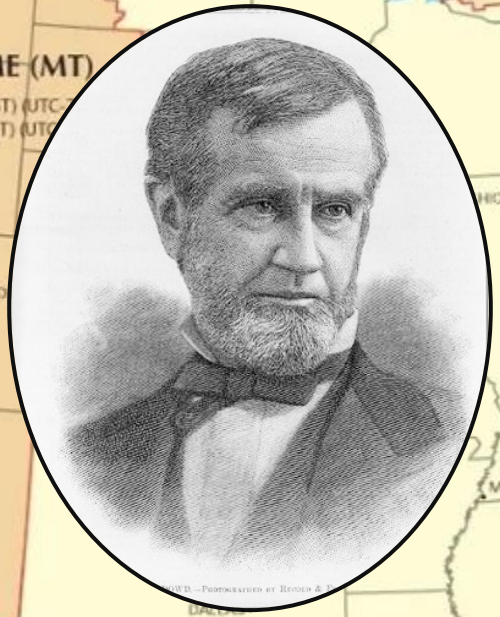
For the first time, we started buying time.



East to West is 60°
4 hours of range

At its peak in the 1800s, the railroads managed timetables in 80 local time zones.

William F Allen



Charles Dowd

PACIFIC TIME (PT)
Pacific Standard Time (PST) (UTC-8).
Pacific Daylight Time (PDT) (UTC-7).

MOUNTAIN TIME (MT)
Mountain Standard Time (MST) (UTC-7)
Mountain Daylight Time (MDT) (UTC-6)

EASTERN TIME (ET)
Eastern Standard Time (EST) (UTC-5)
Eastern Daylight Time (EDT) (UTC-4)

ALASKA TIME
Alaska Standard Time (AKST) (UTC-9)
Alaska Daylight Time (AKDT) (UTC-8)

HAWAII-ALEUTIAN TIME
Hawaii-Aleutian Standard Time (HAST) (UTC-10)
Hawaii-Aleutian Daylight Time (HADT) (UTC-9)

Areas that do not observe Daylight Time

Albers equal area projection

PORTLAND
SALT LAKE CITY
SAN FRANCISCO
LAS VEGAS
LOS ANGELES
PHOENIX
DETROIT
CHICAGO
BOSTON
NEW YORK
WASHINGTON
LOUISVILLE
MEMPHIS
ATLANTA
MIAMI
HONOLULU
ANCHORAGE
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
CANADA
THE BAHAMAS


1883-11-18
12:00:00
MOUNTAIN TIME (MT)
Mountain Standard Time (MST) (UTC-7)
Mountain Daylight Time (MDT) (UTC-6)
PACIFIC TIME (PT)
Pacific Standard Time (PST) (UTC-8).
Pacific Daylight Time (PDT) (UTC-
CENTRAL TIME (
Central Daylight Time
(ET)
(EST) (UTC-5)
(EDT) (UTC-4)
PORTLAND
SAN FRANCISCO
LAS VEGAS
LOS ANGELES
PHOENIX
SALT LAKE CITY
MINNEAPOLIS
CHICAGO
DETROIT
BOSTON
NEW YORK
WASHINGTON
OKLAHOMA CITY
MEMPHIS
ATLANTA
HOUSTON
MIAMI
PACIFIC OCEAN
ATLANTIC OCEAN
GULF OF MEXICO
MEXICO
CANADA
THE BAHAMAS
HONOLULU
ALASKA TIME
Alaska Standard Time (AKST) (UTC-9)
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HAWAII-ALEUTIAN TIME
Hawaii-Aleutian Standard Time (HAST) (UTC-10)
Hawaii-Aleutian Daylight Time (HADT) (UTC-9)
ANCHORAGE
Areas that do not observe Daylight Time
Albers equal area projection

Time Balls

- Used for setting clocks before ship voyages (for longitude)
- Used for residents syncing watches locally.
- Raised up 2 minutes before and dropped at Noon (USA).

On November 18th, 1883 the time balls were dropped twice.

“The Day of Two Noons”


BROADWAY
SPRING 2018
HarryPotterThePlay.com
HAPPY POTTER
TOSHIBA
TDK
#VenetianMo.com


ARCTIC OCEAN
Greenland
(DENMARK)
CANADA
U.S.
UNITED STATES
MEXICO
NORTH PACIFIC OCEAN
NORTH ATLANTIC OCEAN
SOUTH PACIFIC OCEAN
BRAZIL
CHILE
ARGENTINA
SOUTH ATLANTIC OCEAN
RUSSIA
KAZAKHSTAN
MONGOLIA
CHINA
TURKEY
IRAN
ALGERIA
LIBYA
EGYPT
SAUDI ARABIA
INDIA
INDONESIA
AUSTRALIA
INDIAN OCEAN
Coordinated Universal Time (UTC)
formerly Greenwich Mean Time (GMT)


BAD IDEAS
Tessa Violet

1792 AD

Decimal Time

- 1 Day was 10 Decimal Hours
- 1 Hour was 100 Decimal Minutes
- 1 Minute was 100 Decimal Seconds
- 1:23:45 could be written 1.2345h

Daylight Savings Time

1784

Benjamin Franklin

Half-joking suggests we should change clocks to wake up earlier in the Summer to conserve candles.

1895

George Hudson

Suggests we should dial clocks back so everyone can have evening summer-time hobbies like him (bug catching).

1907

William Willett

Felt the British slept in too late in the Summer when they could be working and wanted more sunlight for his evening golfing.

Archduke Franz Fedinand

1918 AD

The Standard Time Act

- Officially instituted the timezones in the USA.
- DST was set for 7 months to conserve energy.
- DST was brought back in World War 2 as “War Time”
- Local jurisdictions optionally kept doing DST until it was standardized in 1966.


Modern Time
Keeping

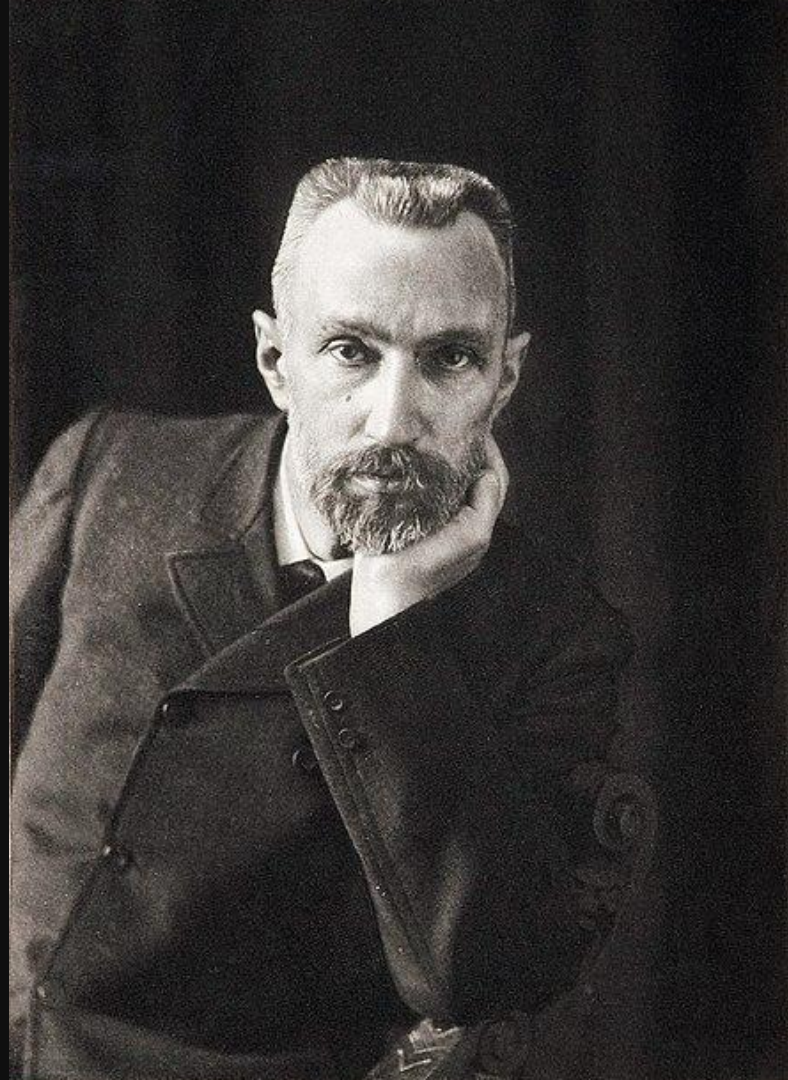
1880 AD
Pierre Curie
Making Quartz Useful

- Half the “Marierre” Curie Power Couple
- Quartz + AC Electricity = Consistent Vibration

1928 - Bell Labs uses this to invent the first quartz clock in

1939 - The Greenwich Observatory goes quartz

Quartz vibrates a million times a second. The new unit of measure is the millisecond.



One Second = 1/86,400th of a day

One Day = 86,400 seconds

1955 AD

L. Essen & J. Parry

Making Caesium Useful

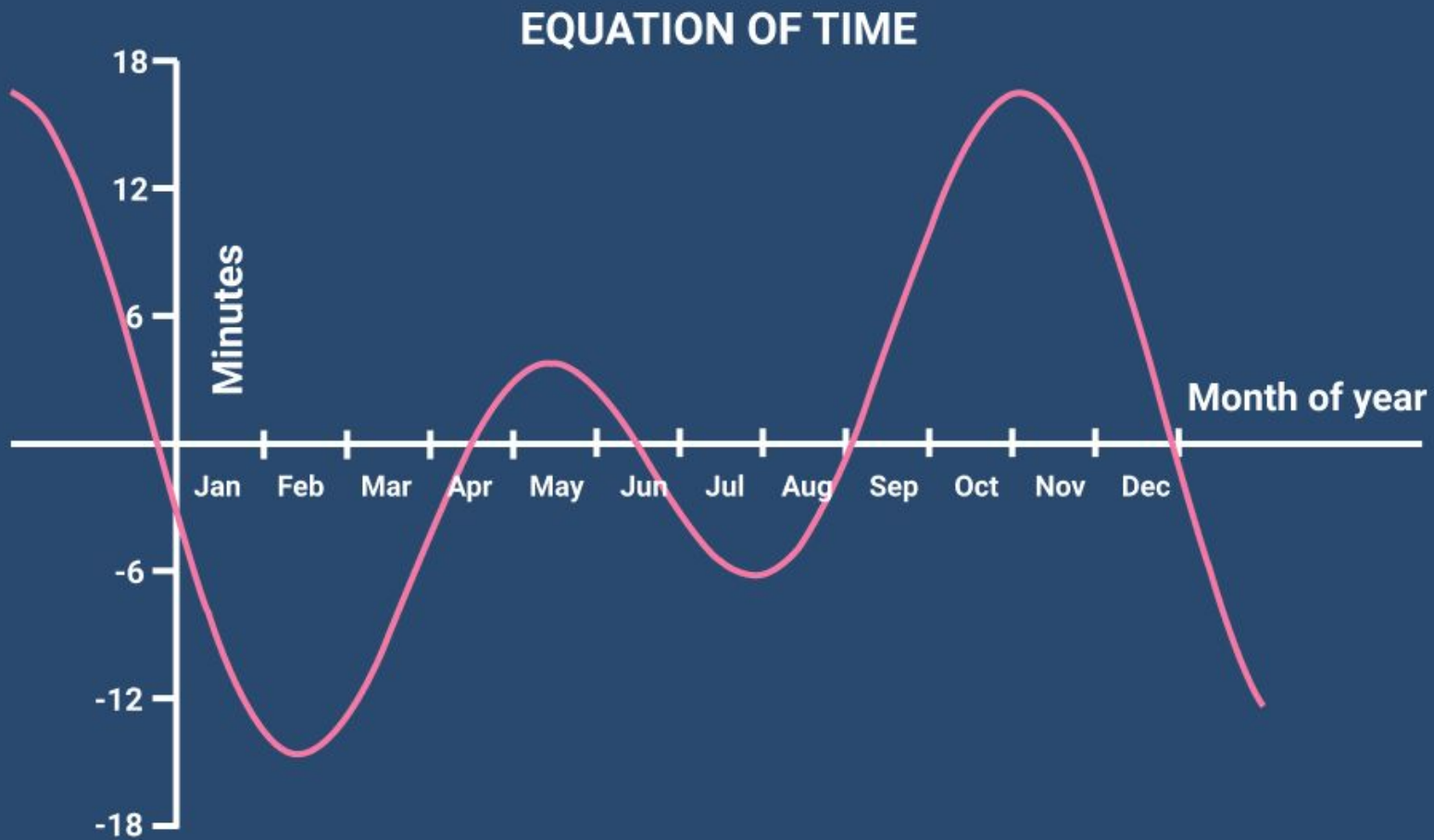
- When energized, , the outer electron of calcium flips magnetically 9,192,631,770 cycles per second.

1967 - The second (and therefore the day) is defined using caesium-133.

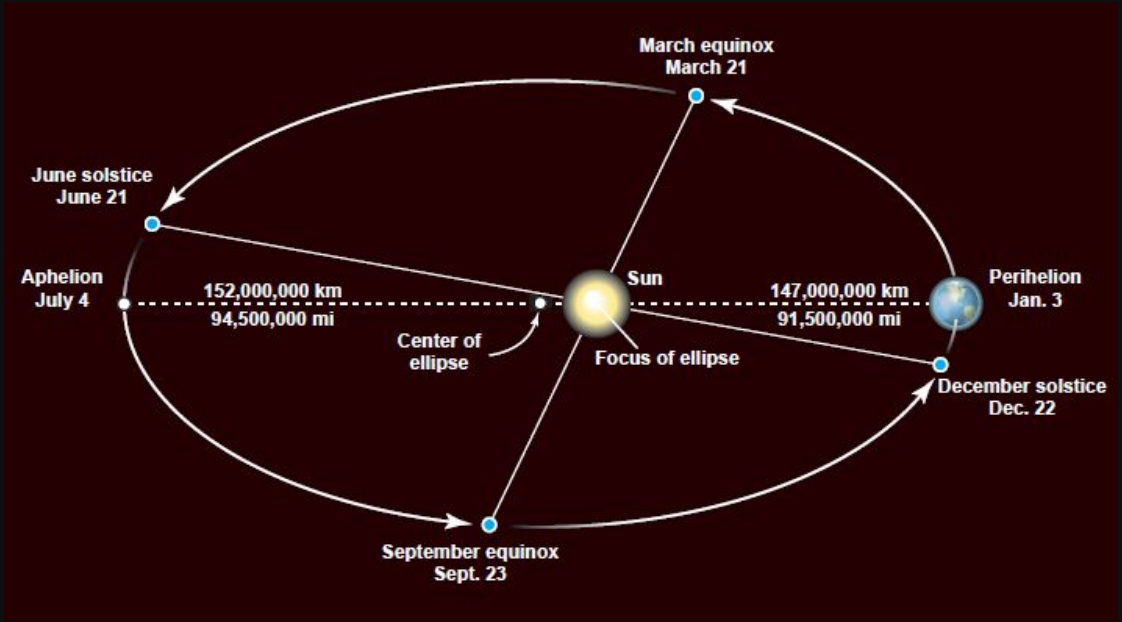
The pendulum has gotten really really fast.


Problems with
Precision

Some Days are Just Longer


EQUATION OF TIME
18
12
6
-6
-12
-18
Minutes
Month of year
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec

Mean Solar Time



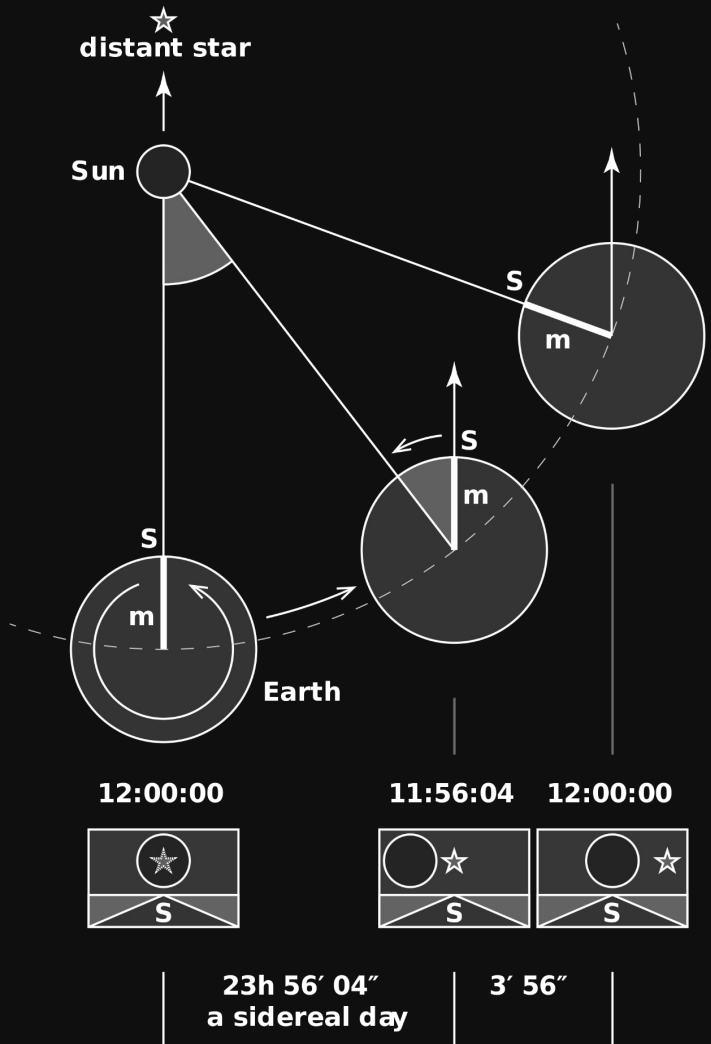
As of 2022, a Mean Solar Day is 86,400.002 seconds

SunQuest Sundial

You Can't Use the Sun to Time the Stars

Sidereal Time

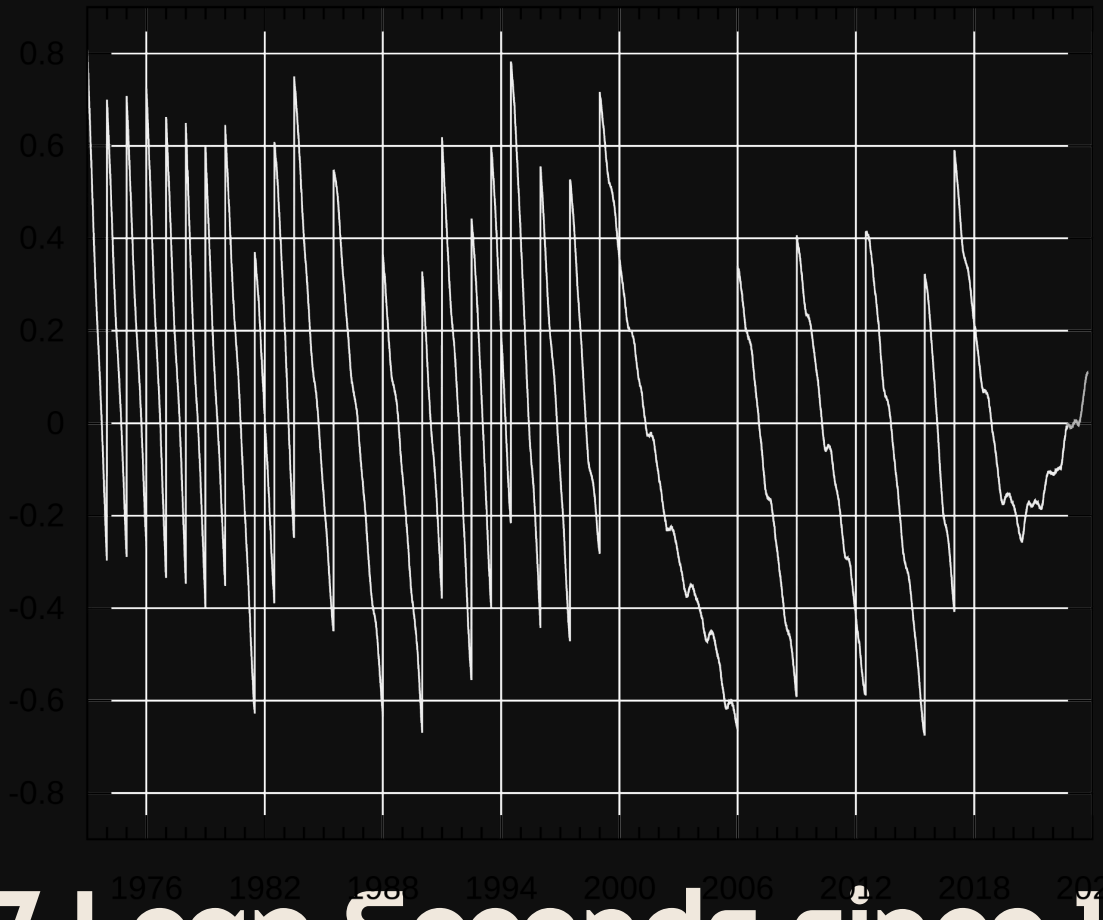
- Time relative to the fixed stars, not the sun.
- A “sidereal day” is 86164.0905s or 23h 56m 4s
- We get one more sidereal day than solar day per year



All Days are Getting Longer

Leap Seconds

- Manage the difference between Ephemeris Time and Solar Mean Time
- Earthquakes and volcanoes impact the speed of the earth's rotation.
- The earth is slowing down by **2.3ms per day per century.**
- Leap seconds are announced 6 months in advance by the ***International Earth Rotation and Reference Systems Service***



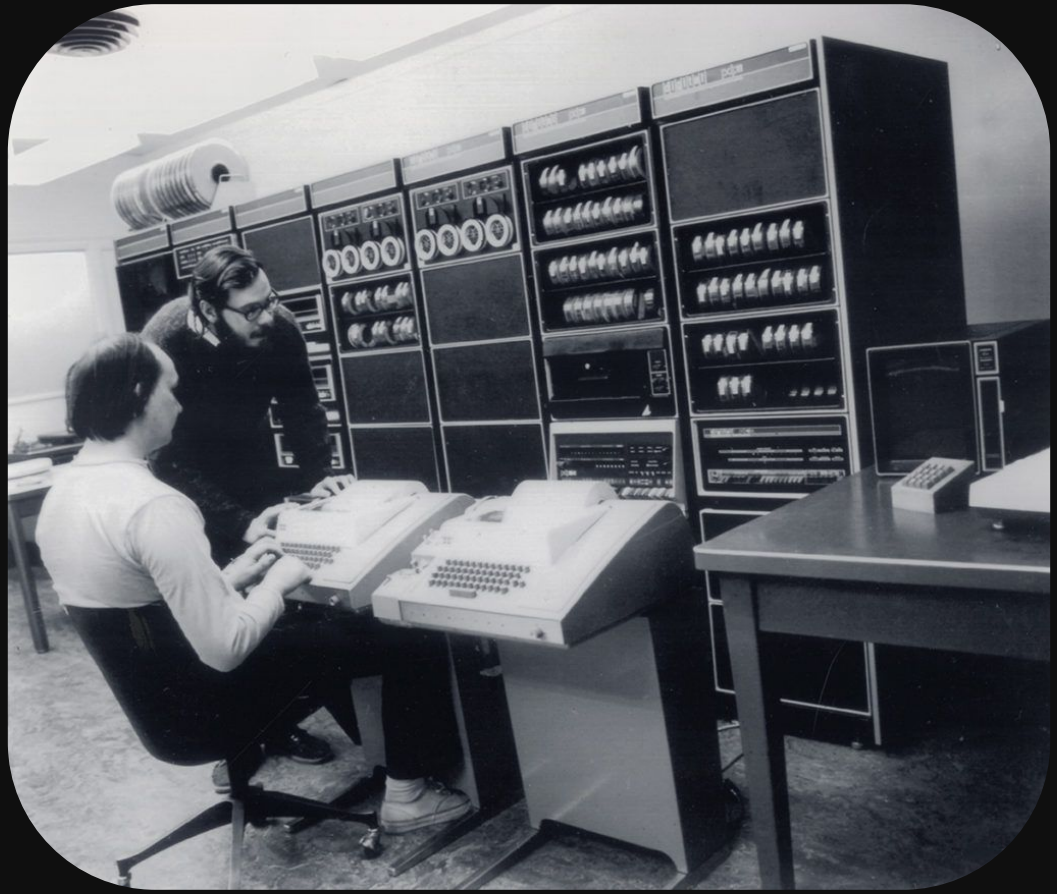
27 Leap Seconds since 1972

23:59:60

TAI	Unsmeared UTC	Smeared time
2022-12-31 12:00:36.000000	2022-12-31 11:59:59.000000	2022-12-31 11:59:59.000000
2022-12-31 12:00:37.000000	2022-12-31 12:00:00.000000	2022-12-31 12:00:00.000000
2022-12-31 12:00:38.000011	2022-12-31 12:00:01.000011	2022-12-31 12:00:01.000000
2023-01-01 00:00:35.499976	2022-12-31 23:59:58.499976	2022-12-31 23:59:58.000000
2023-01-01 00:00:36.499988	2022-12-31 23:59:59.499988	2022-12-31 23:59:59.000000
2023-01-01 00:00:37.000000	2022-12-31 23:59:60.000000	2022-12-31 23:59:59.500005
2023-01-01 00:00:37.500000	2022-12-31 23:59:60.500000	2023-01-01 00:00:00.000000
2023-01-01 00:00:38.000000	2023-01-01 00:00:00.000000	2023-01-01 00:00:00.499994
2023-01-01 00:00:38.500011	2023-01-01 00:00:00.500011	2023-01-01 00:00:01.000000
2023-01-01 00:00:39.500023	2023-01-01 00:00:01.500023	2023-01-01 00:00:02.000000
2023-01-01 12:00:36.999988	2023-01-01 11:59:58.999988	2023-01-01 11:59:59.000000
2023-01-01 12:00:38.000000	2023-01-01 12:00:00.000000	2023-01-01 12:00:00.000000
2023-01-01 12:00:39.000000	2023-01-01 12:00:01.000000	2023-01-01 12:00:01.000000

How Computers Measure Time

Spoiler: It's Stupid



1969

New Years Eve

This Story is possibly not true

This part is completely made up.

1970-01-01 00:00:00

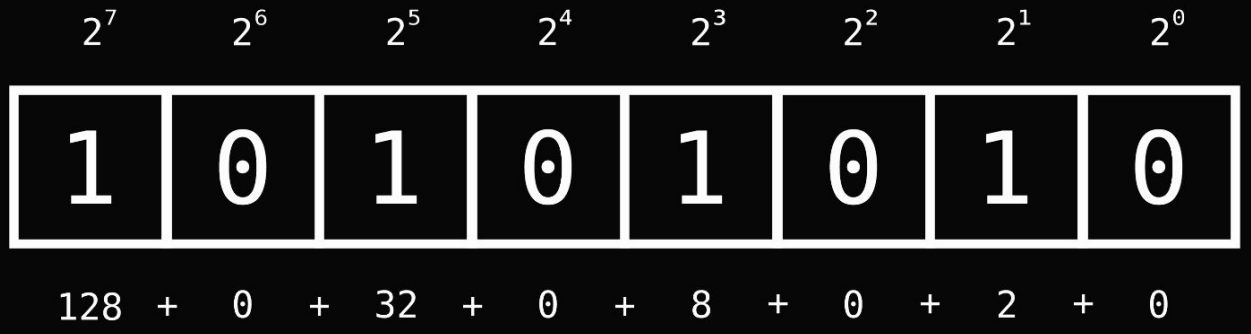
This part is true.

60 Hz

1/60th of a Second

This part is weirdly also true.

The Binary Value of 170



Very true.

4 Bytes

Unsigned

Still true.

0 to $2^{32}-1$

Still true.

2.2 Years

Still true.

November, 1971

Still true.

Seconds

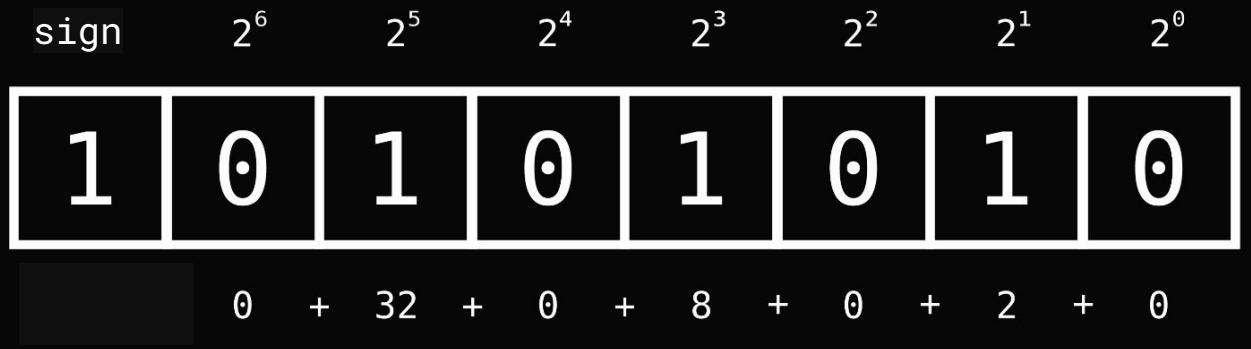
Very true.

4 Bytes

Signed

Still true.

The Binary Value of `-42`



Very true.

-2^{32} to $2^{32}-1$

Still true.

±68 Years

Still true.

1 667 520 900

Still true.

`time_t` Parties

Wed, Oct 17th, 1973 at 6:36:57 PM UTC (1973-10-17)	119 731 017
Sat, Sep 8th, 2001 at 9:46:40 PM EDT	1 000 000 000
Fri, Feb 3rd, 2009 at 6:31:30 PM EST	1 234 567 890
Sun, Sep 13th, 2020 at 8:26:40 AM EDT	1 600 000 000

68 Years

2038-01-19
03:14:07


Epochalypse

Thank You

github.com/x/slides