



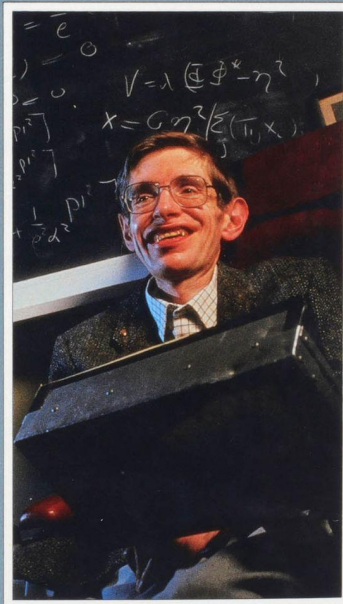
You Depend on Time,
this is how it works,
and you won't believe it

2024-10-29

Philip Rowlands, Jane Street

A BRIEF HISTORY OF TIME

FROM
THE BIG
BANG TO
BLACK
HOLES



STEPHEN W. HAWKING

INTRODUCTION BY CARL SAGAN

You Depend on Time,
this is how it works,
and you won't believe it

2024-10-29

Philip Rowlands, Jane Street



You Depend on Time,
this is how it works,
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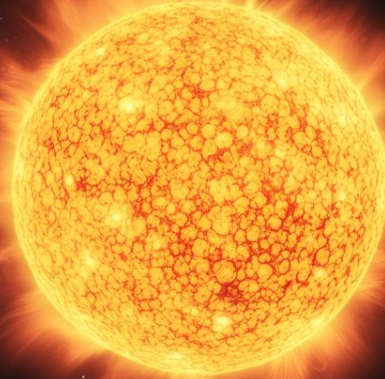
2024-10-29

Tuesday, 29th October, 2024 anno Domini

Tiwesdæg, 3 kalends Blotmonath, 5784 anno Mundi

Philip Rowlands, Jane Street

Part I ~ Calendars



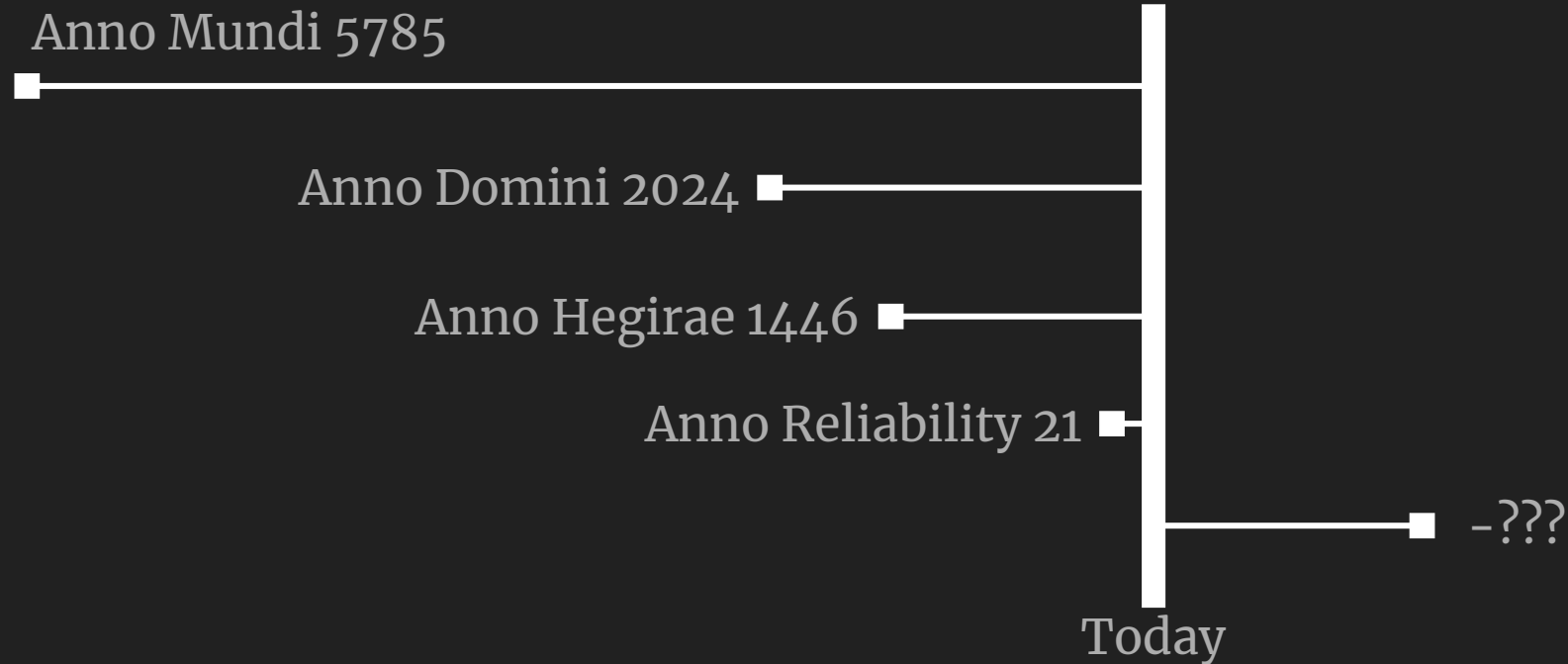


Part I ~ Calendars

YYYY-MM-DD



Epochs



... C MIN
CIO FUNDANO ET
C VETTENNIO SE
VERO COS

SIVANO SACRVM SODN
ETV SETLARN/ADONNM
POSVITTIQVNDIVSANG
LIB FORTVNATVS A
CVRA AMECORVM
IDEMQVE DEDICAVIT
ET EPVVS ADEDIT
DECVRIS NMIII
Y AVGVSTIS EMIN
CIO FUNDANO ET
C VETTENNIO SE
VERO COS

Y AVGVSTIS EMIN
CIO FUNDANO ET
C VETTENNIO SE
VERO COS

Μέτων

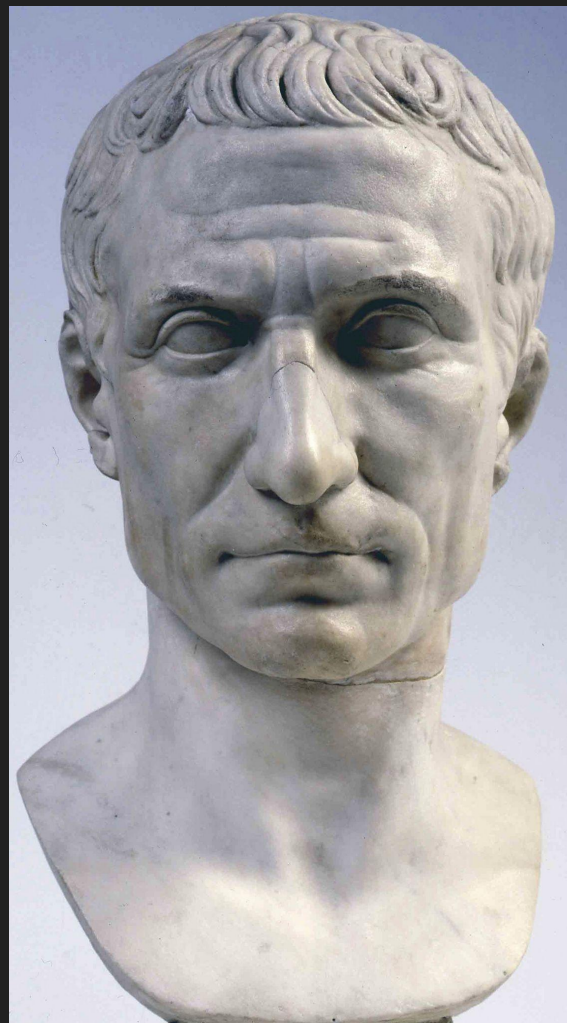
c. 432 BC

- 19-year lunisolar cycle



Julius Caesar

100–44 BC



Dionysius

470–544 AD

- 👍 19-year lunisolar cycle
- AD epoch
- Prediction of Easter, a.k.a. “computus”



Bede

672–735 AD

- 👍👍 19-year lunisolar cycle
- 👍 AD epoch
- 👍 Prediction of Easter



Gregorius XIII

1502–1585

```
bool isLeapYear(int y):
```

1600 ~~1700~~ ~~1800~~ ~~1900~~
2000 ~~2100~~ ~~2200~~ ~~2300~~
etc.





I N T E R gravissimas Pastoralis officij
 à sacro Tridentino Concilio Sedi Aposto-
 tum, Deo adiutore, perducantur. San-
 liquam cogitationem Breuiarij quoque
 clusi rem totam ex ipsius Concilij decretis
 ni Pontificis retulerunt. Duo autem Bre-
 vium preces, laudesq. diuinas festis, per-
 titur, alterum pertinet ad annuos Pasce-
 cursus, Solis, & Luna motu metiendos: Atque illud quidem t



do i buoni & triffi Aspetti de gli pianeti, & far altre operationi, come lui se potrà meglio vcdere, & ancora la quantita dell'horè del giorno.

Ottobre lettera Dñicale G.

Novembre hà giorni 30.

Decembre hà giorni 31.

Festa di Pal. e camp.	D.	H. M.
S. Francesco confid.	4	
	17	
	16	triffo per fluffa
	17	On. bre lettera Dñicale C.
S. Luce Euag.	18	primo quarto 21 31 D.M.
	19	lono per fluffa
	20	bono per fluffa
	21	triffo per fluffa
	22	triffo per fluffa
	23	
	24	
	25	
	26	Luna nuova 27 30 D.M.
	27	
S. Simone & Giuda Apolloli	28	
	29	bono per fluffa
	30	bono per fluffa
Pal. e campid.	31	

t += 10

la Festa di tutto il finit.	D.	H. M.
la Gerememo	1	triffo per fluffa
22 Oct dei de- fanti.	2	secondo quarto 12 18 D.M.
	4	
	5	bono per fluffa
	6	
fluffa di Pal. e campid.	7	bono per medicina
Pal. e camp.	9	
S. Martino ve- fteco e colif.	10	Piena 11 19 D.M.
	11	
	12	
	13	bono per medicina
	14	bono per medicina
	15	
	16	
Pal. e camp.	17	Primo quarto 17 5 D.M.
	18	
	19	triffo per fluffa
Pal. e camp.	20	
	21	
Pal. e camp.	22	lono per medicina
Campid.	23	
	24	
S. Chacurg. e mari.	25	Luna Nuova 26 11 D.M.
	26	
	27	bono per fluffa
	28	
	29	triffo per fluffa
S. Andrea Ap.	30	

D.	H. M.
1	
2	Secundo quarto 17 30 N. S.
3	
4	bono per medicine
5	
6	Pal. e campid.
7	Pal. e campid.
8	fluffa di Pal. e camp. Piena
9	
10	
11	
12	
13	S. Lucia virg. e mari.
14	
15	Quarto temp. Pora.
16	primo quarto 11 11 N. S.
17	Quattro temp.
18	triffo per fluffa
19	
20	
21	S. Thomasfo Apollolo.
22	
23	Luna Nuova 23 16 N. S.
24	
25	Nati del N. S.
26	bono per medicina
27	S. Gio. Euag.
28	triffo per fluffa
29	
30	
31	medicore per medicine

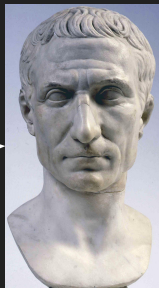
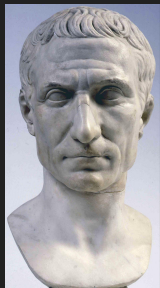
O T T O B R E.

N O V E M B R E.

D E C E M B R E.

Nicholson

1655–1727



Karl XII

Year	Gregorian	Carolian
1700	J+11	J+1
1704	J+11	J+2
1708	J+11	J+3
1712	J+11	J+4
...		
1736	J+11	J+10
1740	J+11	J+11



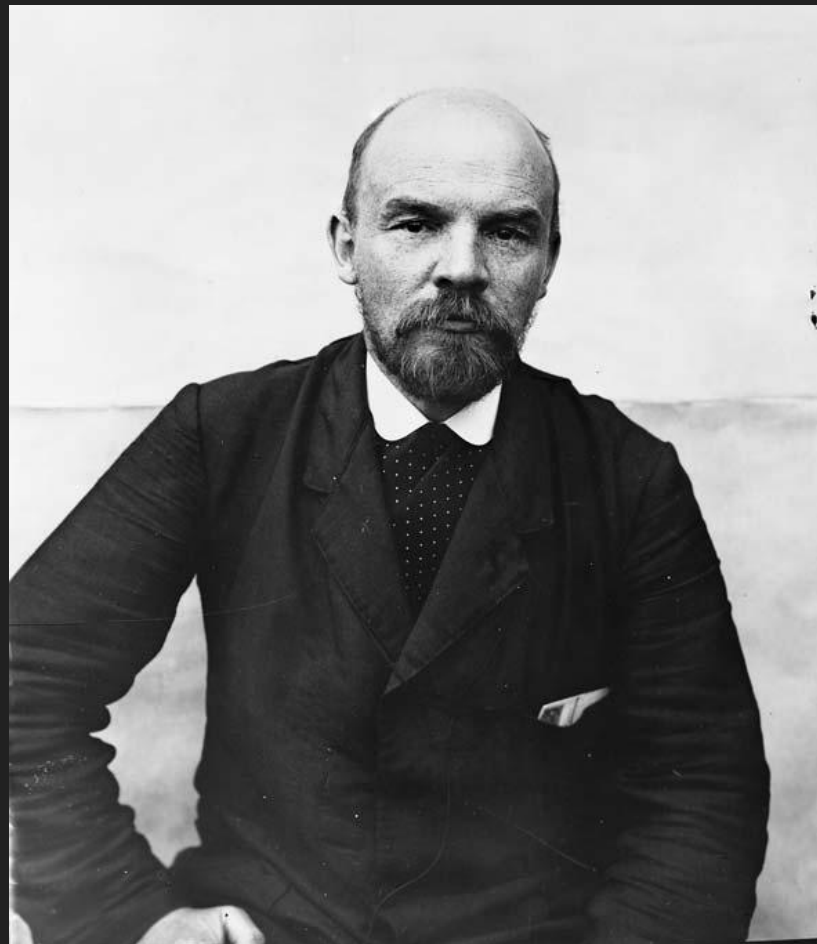
Karl XII

Year	Gregorian	Carolian
1700	J+11	J+1
1704	J+11	J+2
1708	J+11	J+3
1712	J+11	J+0
...		
1736	J+11	J+10
1740	J+11	J+11



Ленин

1870–1924





Part I ~ Calendars

YYYY-MM-DD

Month

Martius
Aprilis
Maius
Iunius
Quintilis
Sextilis
September
October
November
December
???

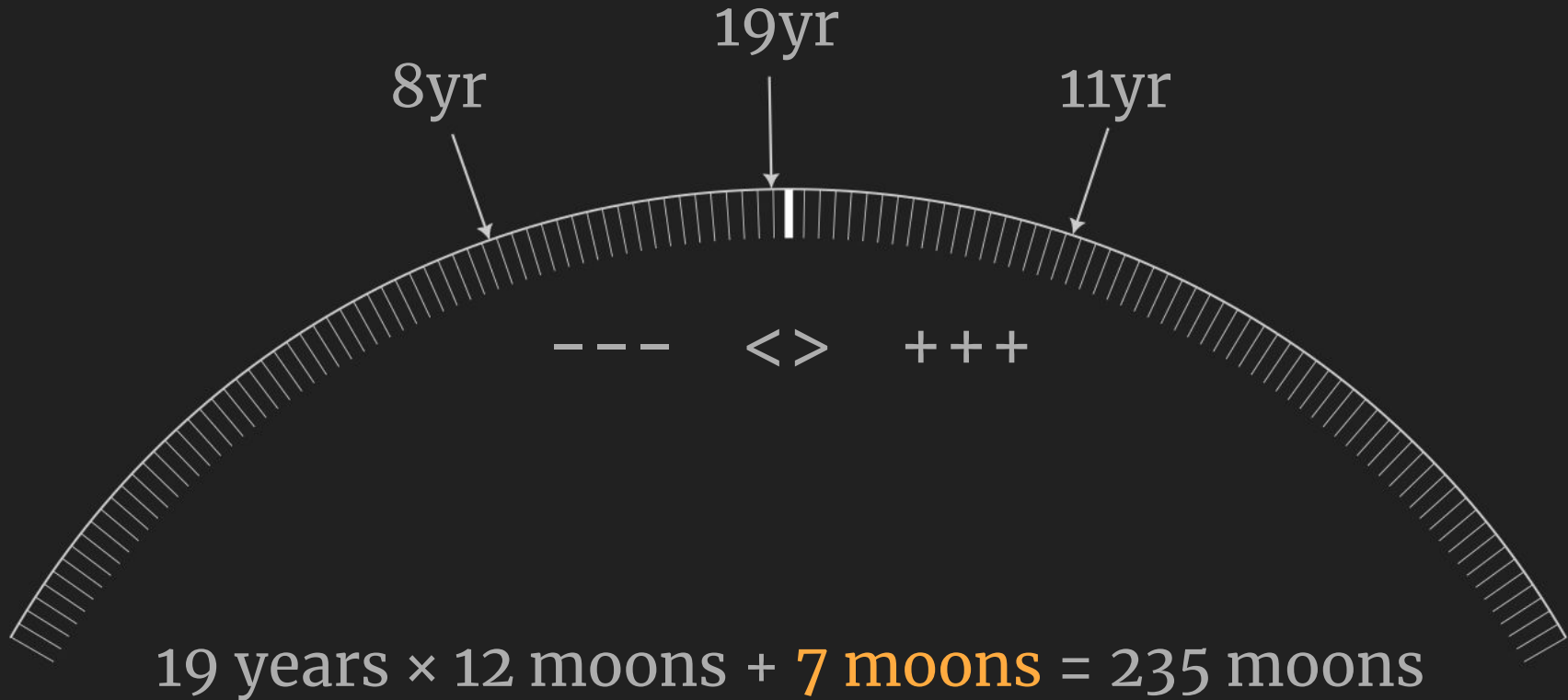


Ianuarius
Februarius
Martius
Aprilis
Maius
Iunius
Quintilis
Sextilis
September
October
November
December



Ianuarius
Februarius
Martius
Aprilis
Maius
Iunius
Iulius
Augustus
September
October
November
December

Lunisolar

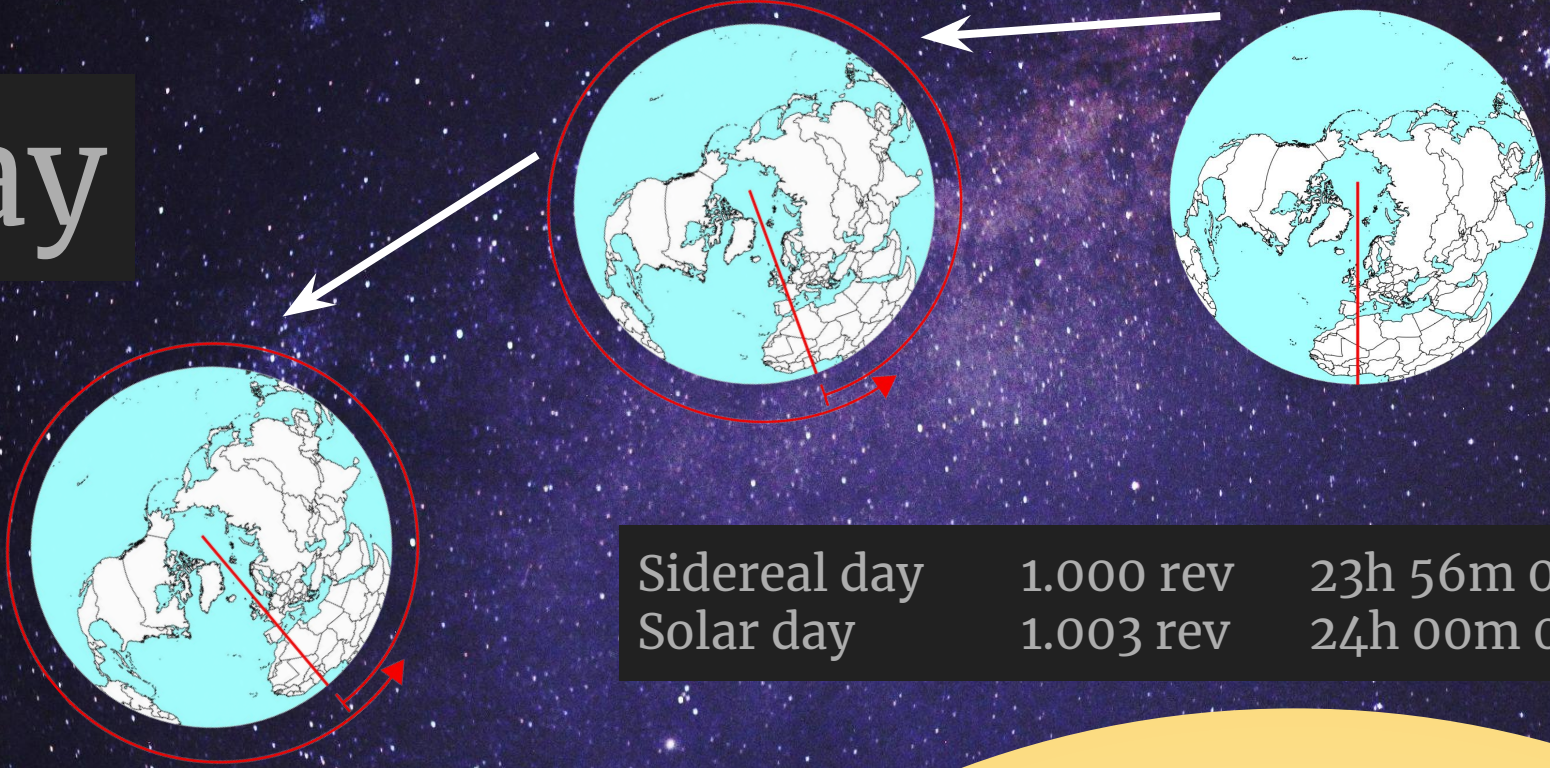




Part I ~ Calendars

YYYY-MM-DD

Day



Sidereal day	1.000 rev	23h 56m 04s
Solar day	1.003 rev	24h 00m 00s

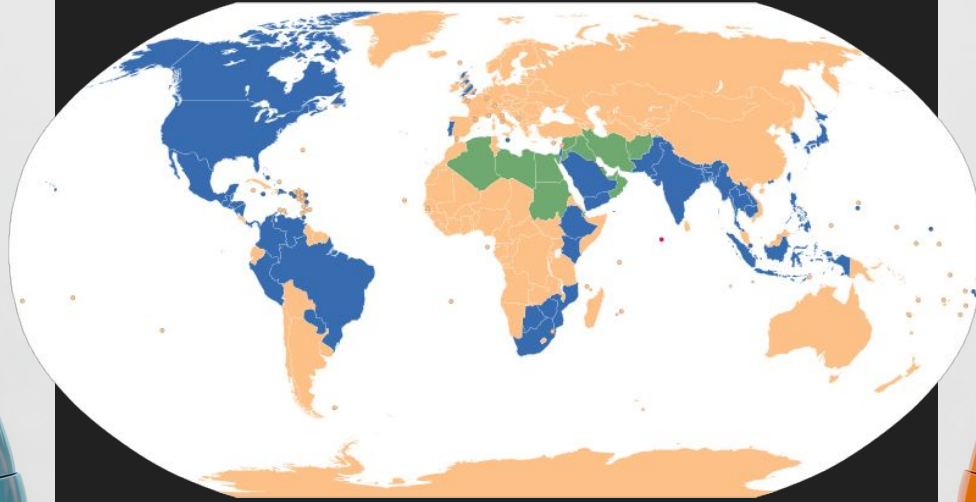
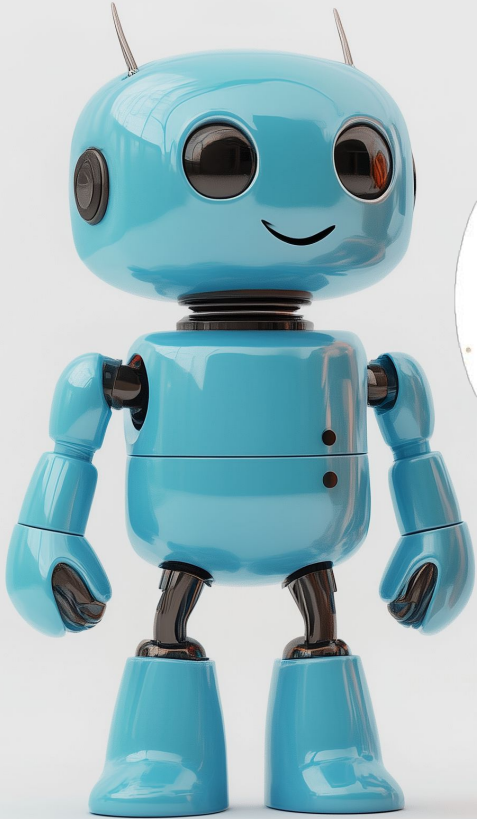
Week / Classical planets



Week

<i>Latin</i>	<i>English</i>	<i>Old Saxon</i>
Solis	Sunday	Sunnundag
Lunae	Monday	Manundag
Martis	Tuesday	Tiuwesdag
Mercurii	Wednesday	Wodanesdag
Iovis	Thursday	Thunaresdag
Veneris	Friday	Friadag
Saturni	Saturday	Satarnesdag

Sunday 1st!



Dé Céadaoin / Wed

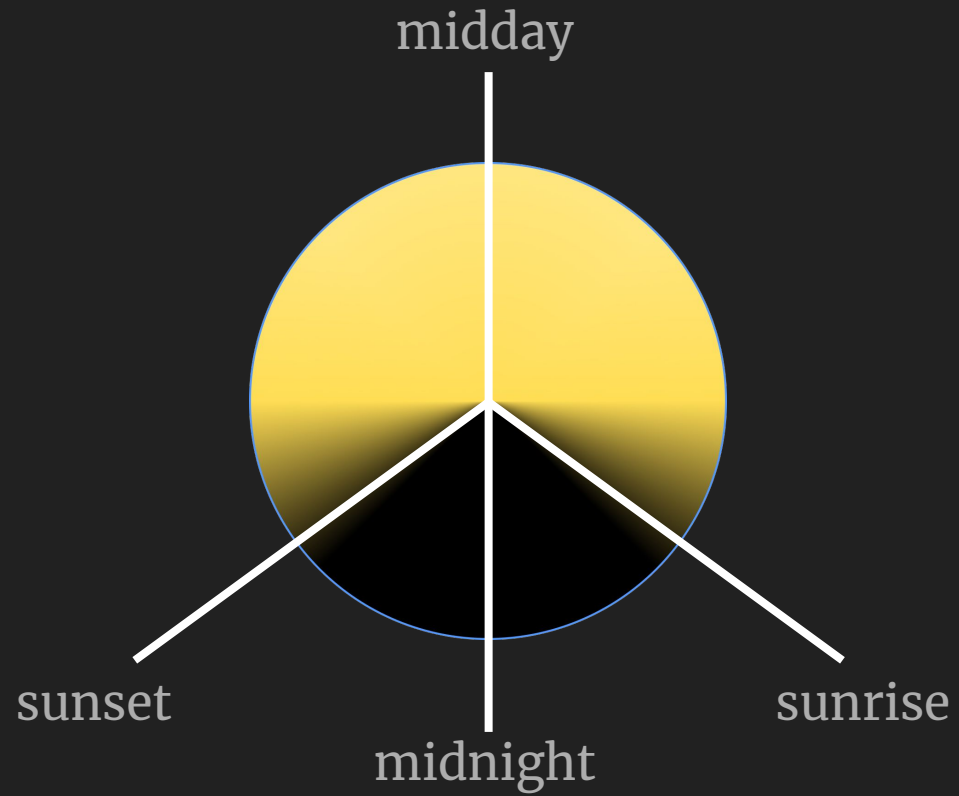
Déardaoin / Thu

Dé hAoine / Fri

Monday 1st!

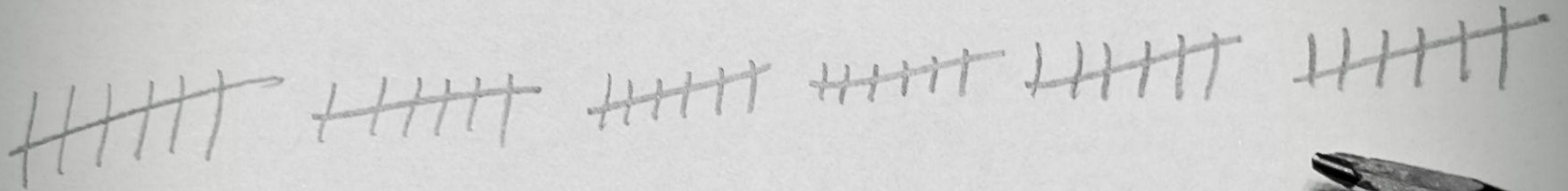


Boundaries



N₁ Y₄ C₃ H₄ T₁ H₄ E₁ M₃ E₁ R₁ O₁ N₁

Tuesday
29th October
2024 anno Domini



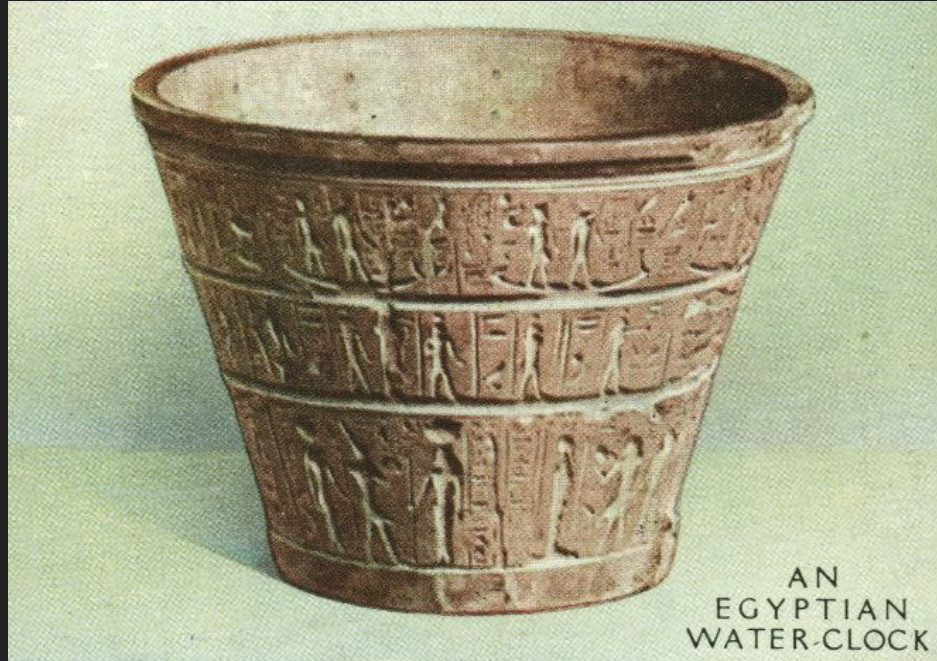
Part II ~ Clocks



Shishi-
odoshi
鹿威し



Klepsydra



Sundial



Hourglass, Candle



Verge & Foliot



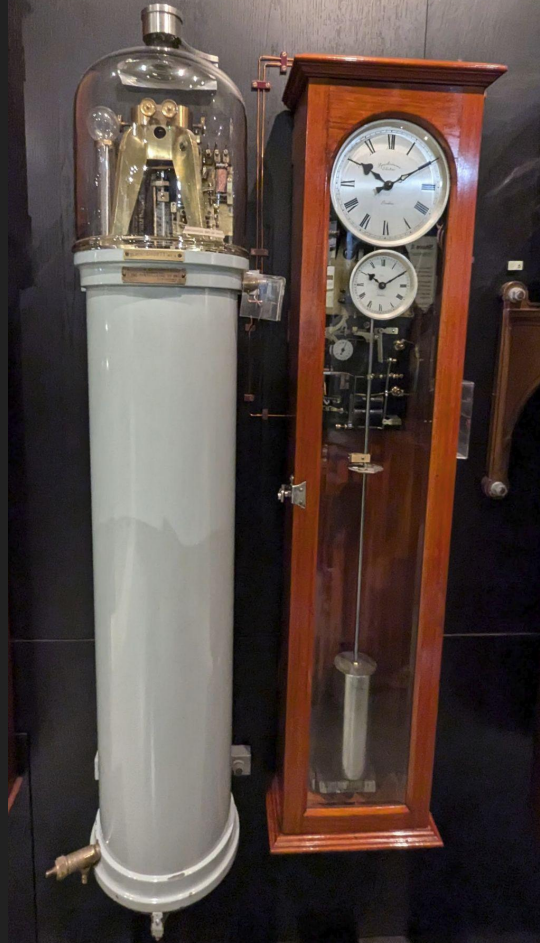
Balance Wheel / Spring



Pendulum



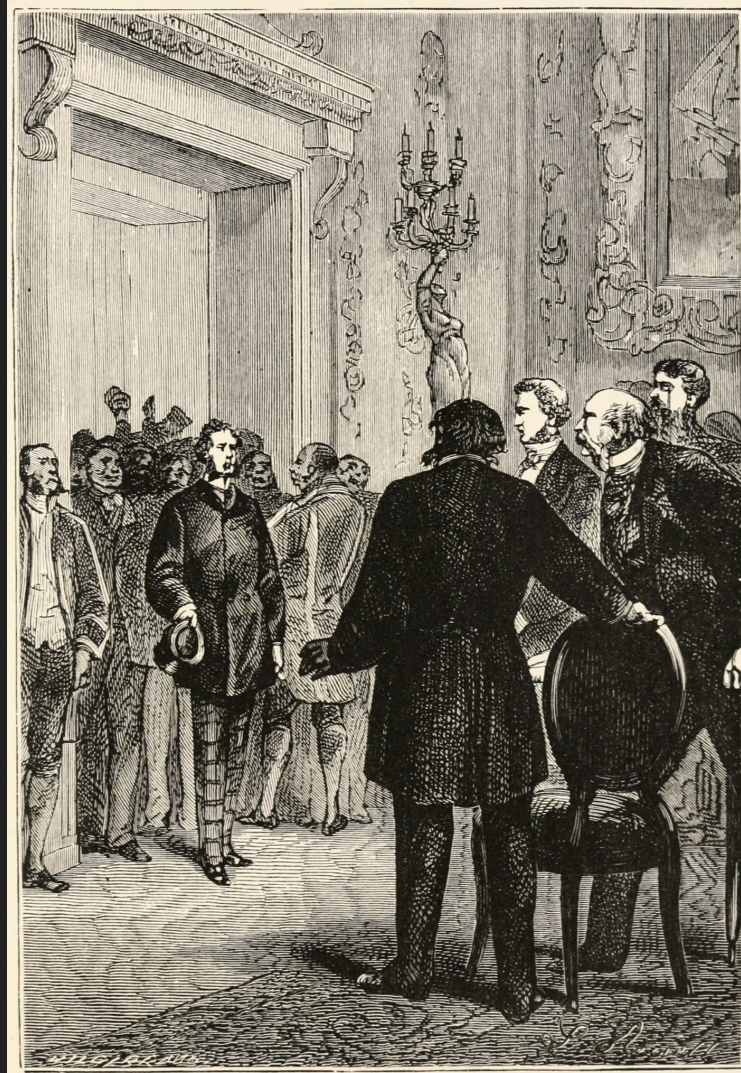
Shortt vacuum pendulum



Clocks in fiction

At the fifty-seventh second the door of the saloon opened; and the pendulum had not beat the sixtieth second when Phileas Fogg appeared, and in his calm voice, said, "Here I am, gentlemen!"

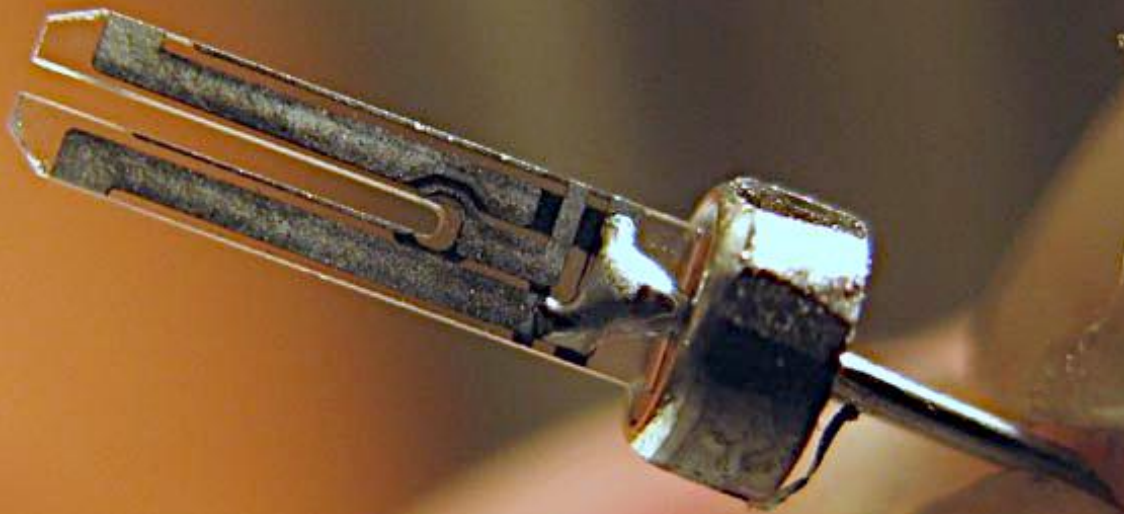
Around the World in Eighty Days
Jules Verne, 1872



Tuning fork



Quartz



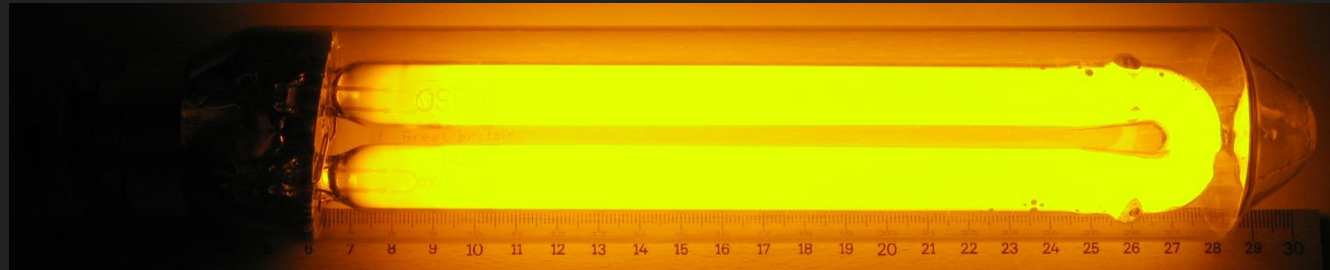
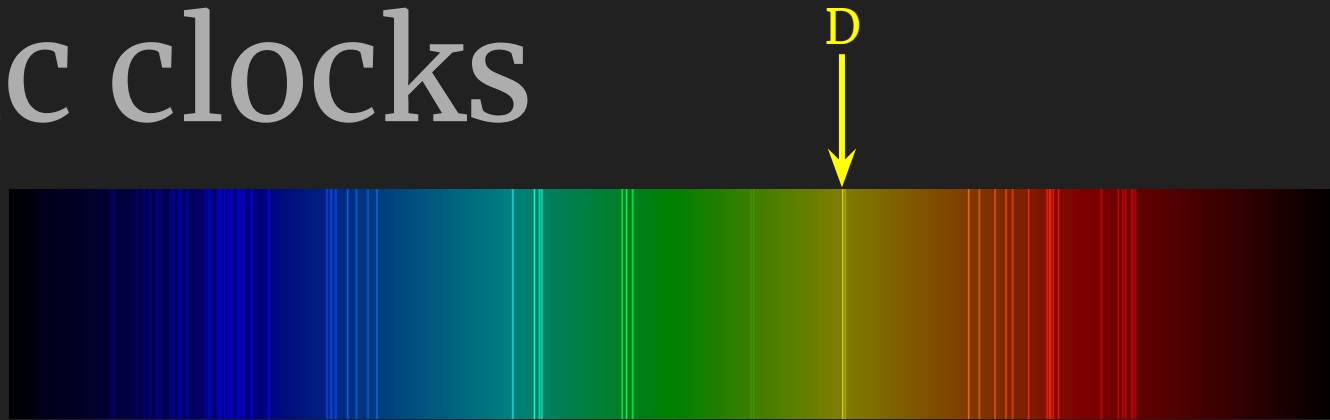
Atomic clocks

$$2.105 \text{ eV} == 0.33 \text{ fJ}$$

$$\begin{aligned}\lambda &= hc/E \\ &= 590 \text{ nm}\end{aligned}$$

$$\begin{aligned}t &= \lambda/c \\ &= 1.968 \text{ fs}\end{aligned}$$

$$1/t = 508 \text{ THz}$$



Atomic clocks

9192631770 Hz

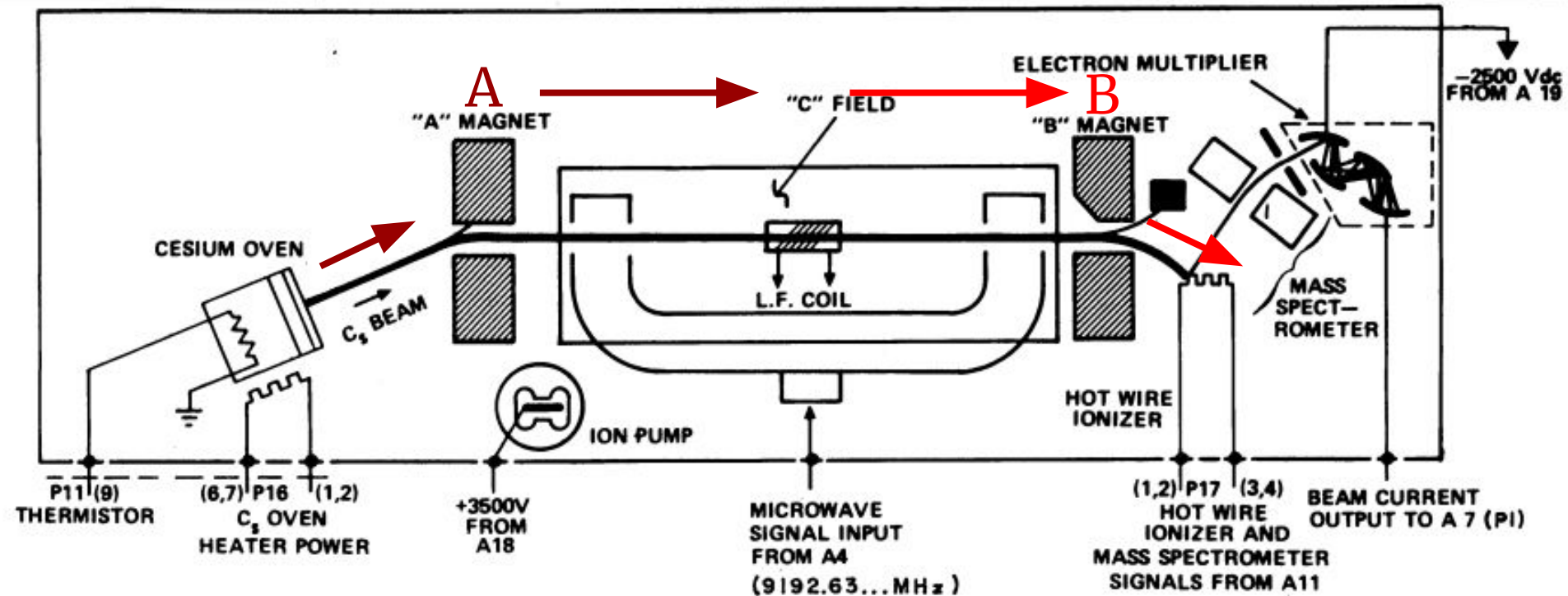
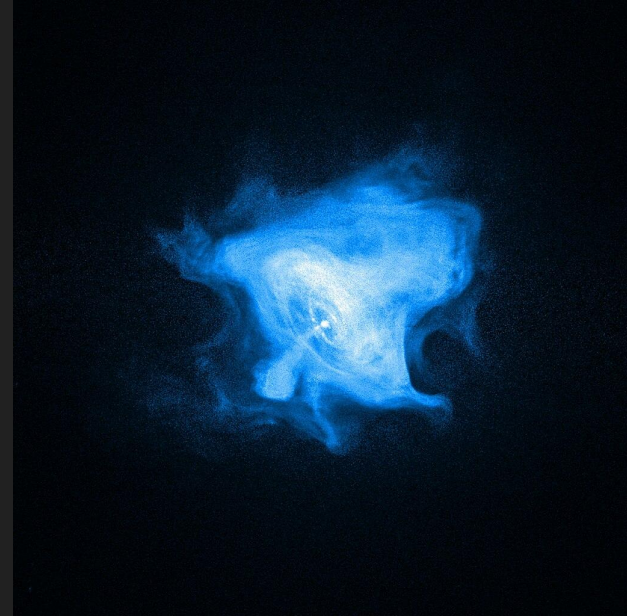


Figure 4-42. Beam Tube Schematic

Clocks in space



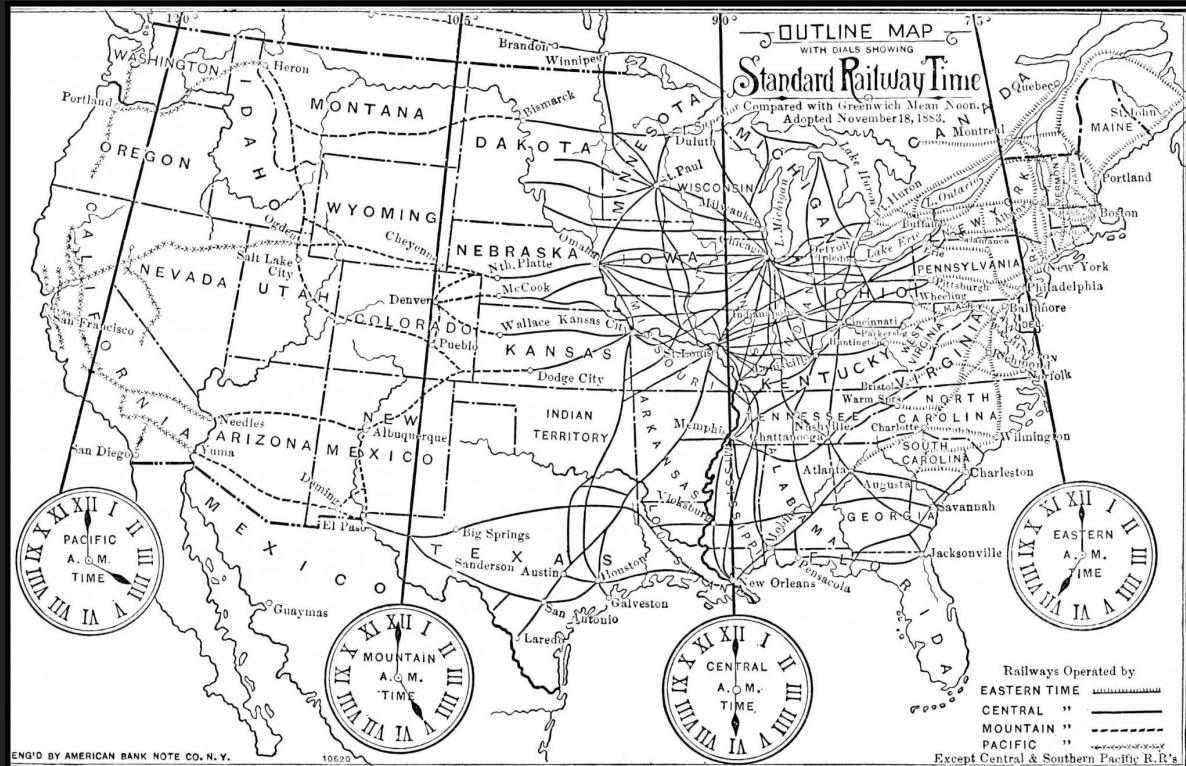
Synchronization



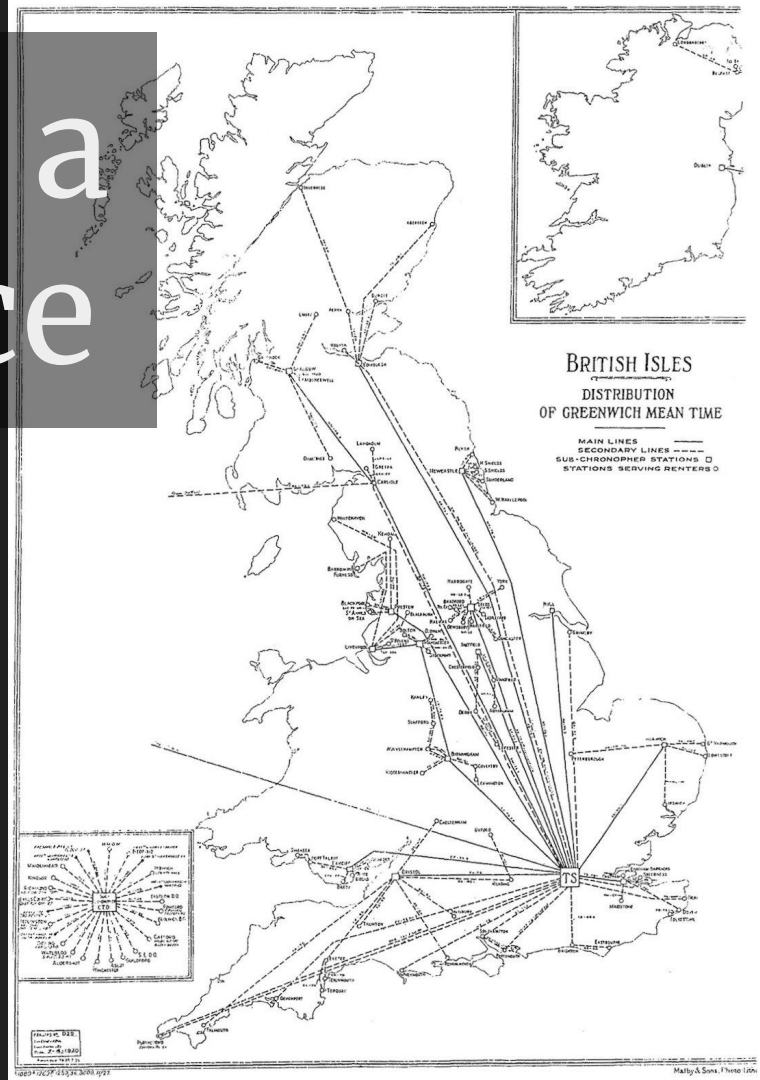
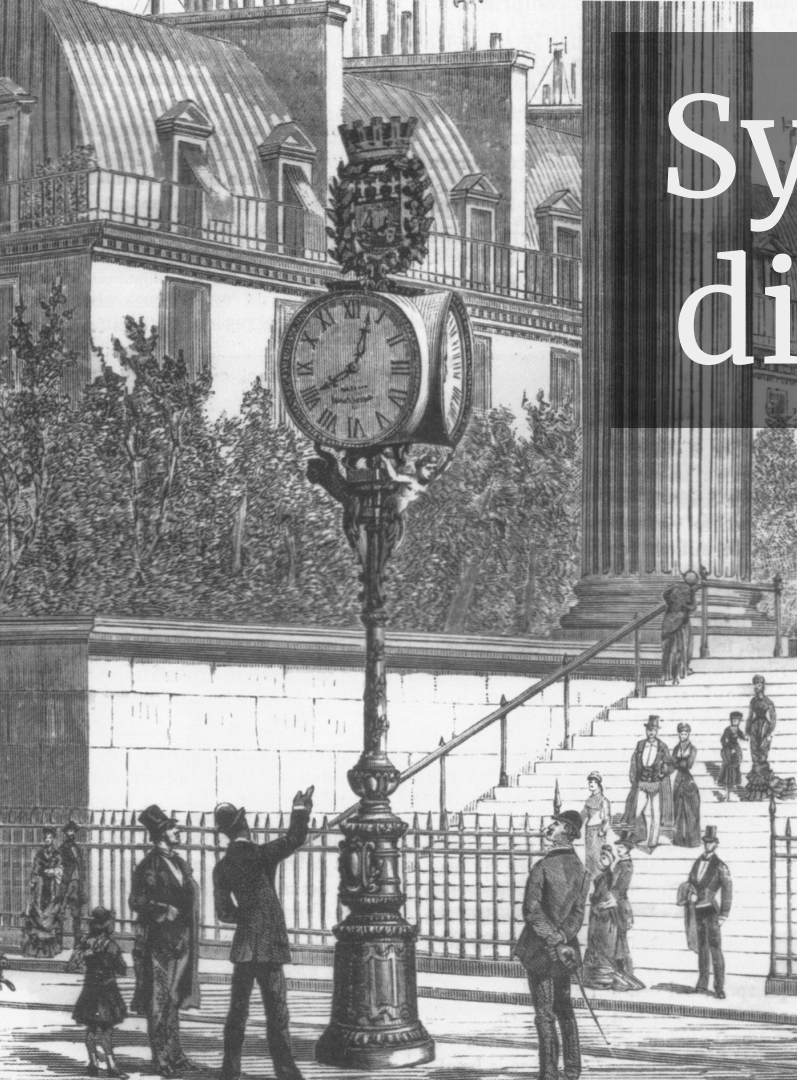
Ruth Belville



Standard Time

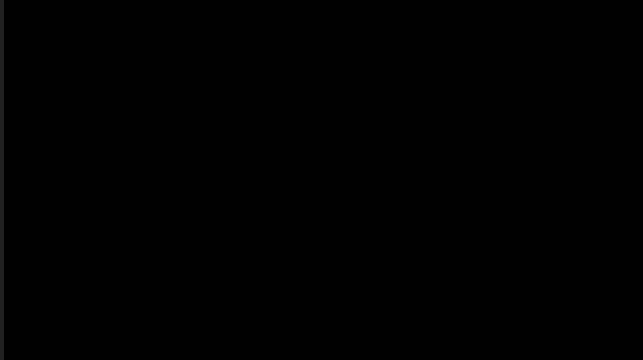


Sync at a distance

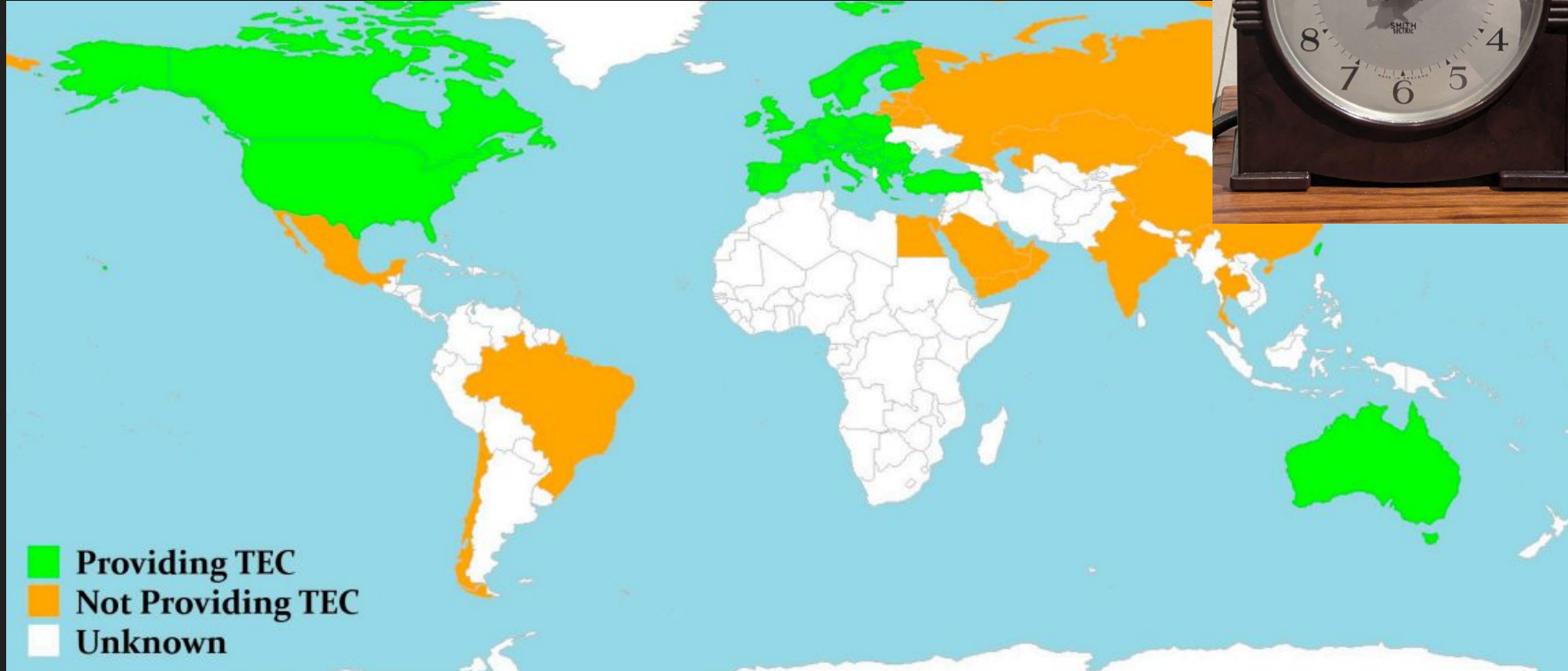


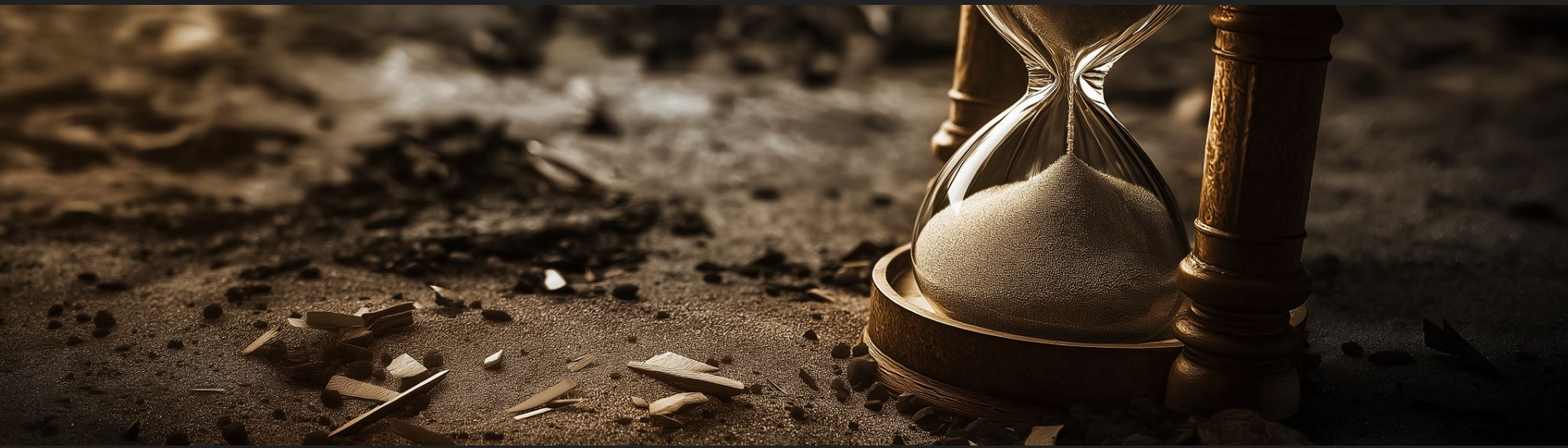
Radio

- Pips
- Constant radio signal



Utility Frequency





Part III ~ Computers



RDTSC

Read Time Stamp Counter

```
uint64_t gettime() {  
    uint64_t time = __rdtsc();  
    return time;  
}
```

```
$ objdump -d gettime.o  
<gettime>:  
    rdtsc  
    shl rdx,0x20  
    or  rax,rdx  
    ret
```

CPUID

```
$ cpuid -1l 0x16
```

```
CPU:
```

```
Processor Frequency Information (0x16):
```

```
Core Base Frequency (MHz): 0xc1c (3100)
```

```
Core Maximum Frequency (MHz): 0xe10 (3600)
```

```
Bus (Reference) Frequency (MHz): 0x64 (100)
```

```
Advanced Power Management Features (0x80000007/edx):
```

```
TscInvariant = true
```

RFC 868 / rdate

```
$ rdate -p time.nist.gov  
Tue Oct 15 00:59:10 BST 2024
```

```
$ rdate -p time.nist.gov  
Tue Oct 15 01:01:36 BST 2024
```

Postcard Time Protocol



POSIX API (easy mode)

```
$ strace ./toy_time
```

```
time(NULL) = 1729020973 (2024-10-15T19:36:13+0100)
```

POSIX API (μ s mode)

```
$ strace ./toy_gettimeofday  
gettimeofday({tv_sec=1729022043, tv_usec=920849}, NULL) = 0
```

```
$ cat /proc/PID/maps
```

```
...  
7f1b078f0000-7f1b078f2000 r-xp 00000000 [vdso]
```

VDSO

```
$ file vdso.dump
```

```
vdso.dump: ELF 64-bit LSB shared object, x86-64, version 1 (SYSV),  
dynamically linked, stripped
```

```
$ objdump -T vdso.dump
```

```
vdso.dump: file format elf64-x86-64
```

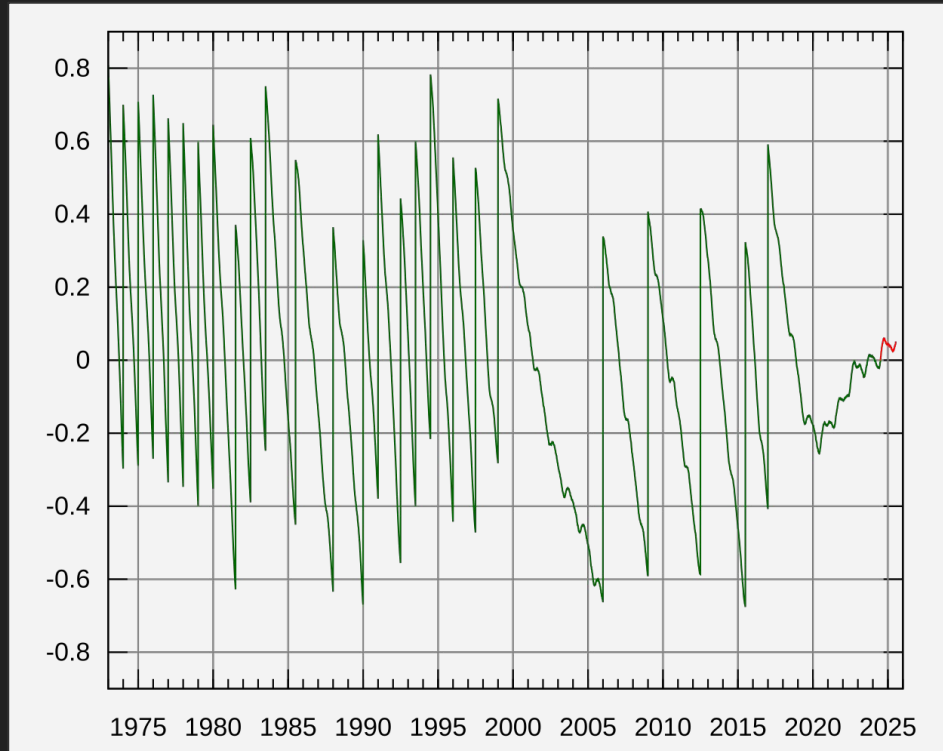
DYNAMIC SYMBOL TABLE:

0000000000000af0	w	DF	.text	00000000000003a6	LINUX_2.6	clock_gettime
0000000000000ea0	w	DF	.text	0000000000000063	LINUX_2.6	clock_getres
00000000000007d0	w	DF	.text	00000000000002e2	LINUX_2.6	gettimeofday
0000000000000ac0	w	DF	.text	000000000000002e	LINUX_2.6	time
0000000000000f10	w	DF	.text	000000000000002a	LINUX_2.6	getcpu

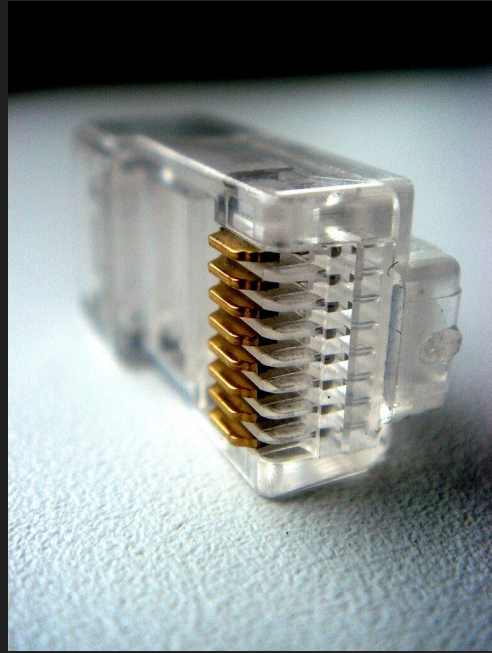
POSIX API (ns mode)

```
$ strace ./toy_clock_gettime
clock_gettime(CLOCK_REALTIME,
  {tv_sec=1729024803, tv_nsec=557330460}) = 0
clock_gettime(CLOCK_MONOTONIC,
  {tv_sec=847635, tv_nsec=834750095}) = 0
##### Linux only #####
clock_gettime(CLOCK_BOOTTIME,
  {tv_sec=847635, tv_nsec=835235356}) = 0
clock_gettime(CLOCK_TAI,
  {tv_sec=1729024840, tv_nsec=559715916}) = 0
```

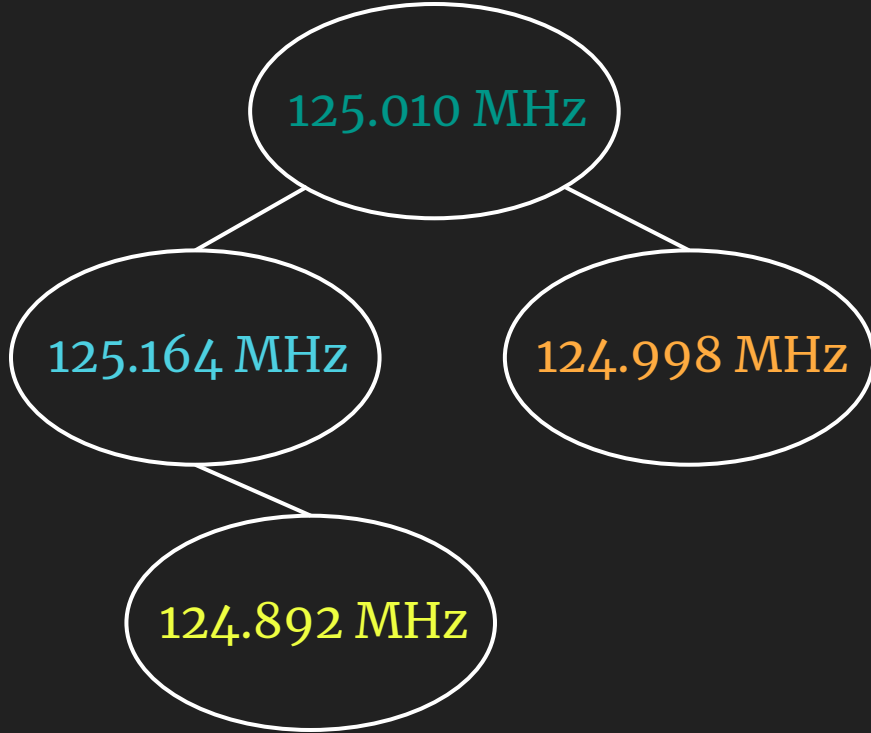
Leap seconds



Digital synchronization



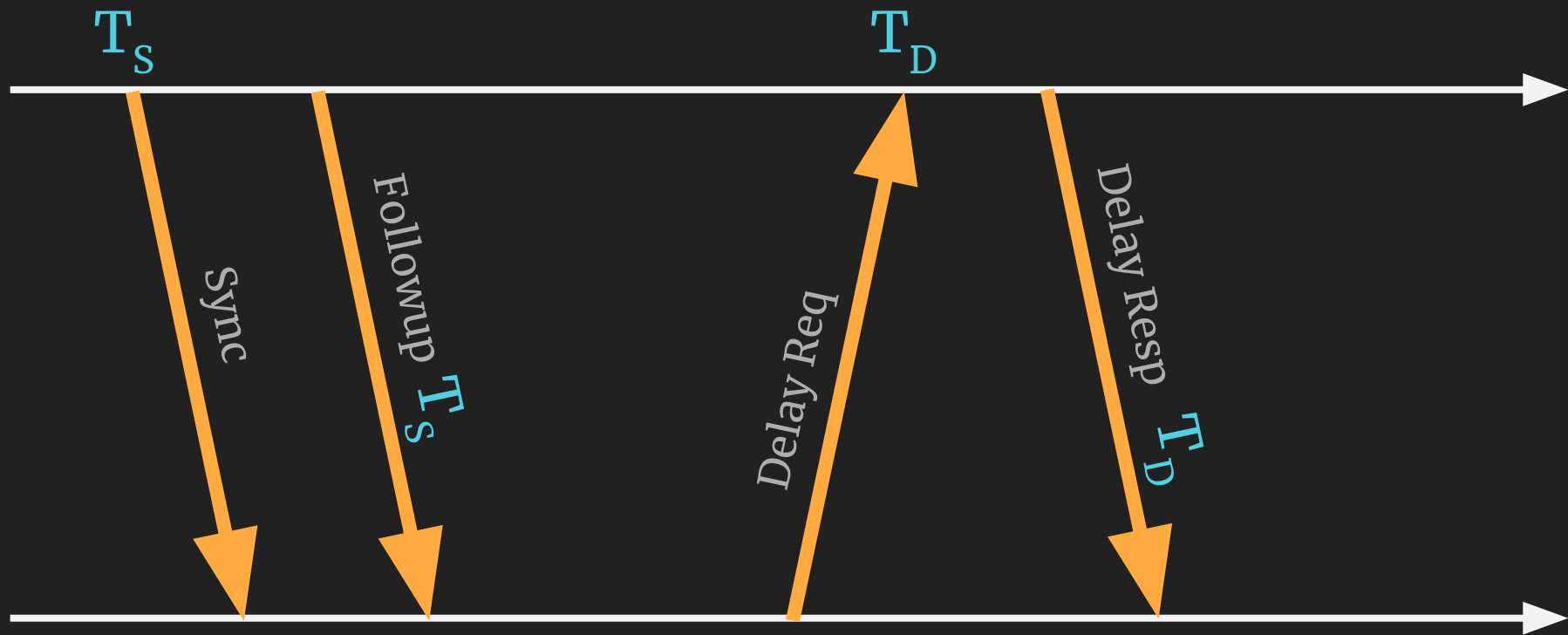
non-SyncE



SyncE



Precision Time Protocol



Pocket watch

- GSM NITZ
- GPS / GNSS
- NTP
- Manual config





AUG CALIFORNIA CA 86
N 52854
OUTATIME
The Golden State