## Optical clocks

What time is it?

## Optical Frequency Comb



## Better clocks, picking up the story circa 1900

## John Harrison \& Longitude



H1

## Train chronometer

- 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



## More oscillations, more accuracy

- Grandfather clock, 1 swing per second
- Mechanical watch, ~3 rotations per second


## Quartz clocks

- Electric resonance, typically 32,768 beats/second
- Invented 1927, quickly surpassed mechanical clocks in accuracy
- Quartz watches 1969


Quartz time standard, 1929


## French Quartz Marine Chronometer

- 4.19 million oscillations per second (4.19 MHz)


Atomic clocks,
~1955

- cesium
- rubidium
- hydrogen maser


9,192,631,770 oscillations/second

## What time is it?

## Observing stars to measure local time



## Why we used stars

- The rotation of the Earth is very consistent
- Until atomic clocks, the Earth's rotation was the most accurate measure of time


## 1960's

- Atomic time is more accurate
- Leads to several measures of time


## What time is it?

- International Atomic Time (TAI)
- Universal Time (UT1)
- UTC (Coordinated Universal Time)


## International Atomic Time (TAI)

- Is determined using atomic clocks
- Is very accurate
- The time of noon wanders




## UT1

- Is the rotation of the Earth
- The Earth's rotation speeds up and slows down
- Time of a second wanders



# Internetfonal Earth Rotation and Reference Systems Service 



## Coordinated Universal Time (UTC)

- Most common time
- The second is given by atomic time
- Leap seconds are occasionally inserted to keep noon from being more than a second off
- Pro: lines up more or less with both atomic and celestial time
- Used for almost all common usages of time
- Not actually useful for precision work


## Optical clocks

Counting very fast ( $\sim 100$ trillion times per second)

## Many fancy lasers



## Optical Frequency Comb



## Optical Frequency Comb


#### Abstract

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## Optical clock




