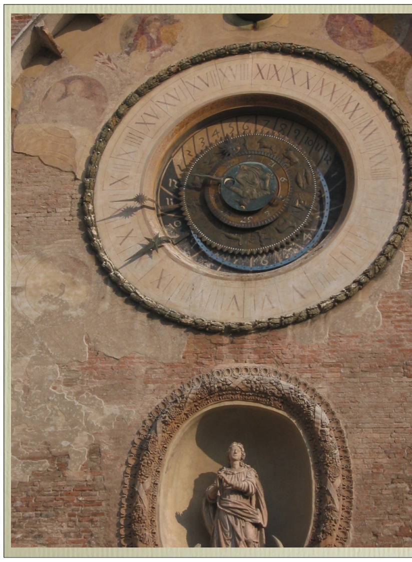


# Measurement of Time

Peter Watson

## "My Grandfather's Clock"

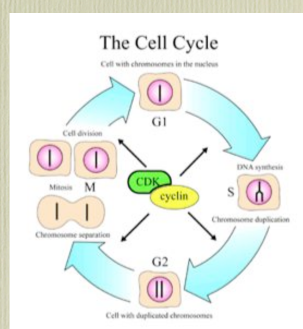
My grandfather's clock
Was too large for the shelf,
So it stood ninety years on the floor;
It was taller by half
Than the old man himself,
Though it weighed not a pennyweight more.
It was bought on the morn
Of the day that he was born,
And was always his treasure and pride;
But it stopped short
Never to go again,
When the old man died.
CHORUS:
Ninety years without slumbering,
Tick, tock, tick, tock,
His life seconds numbering,
Tick, tock, tick, tock,
It stopped short
Never to go again,
When the old man died.

## When did time start to matter?

Work, eat, play, mate

- Sleep, play, mate

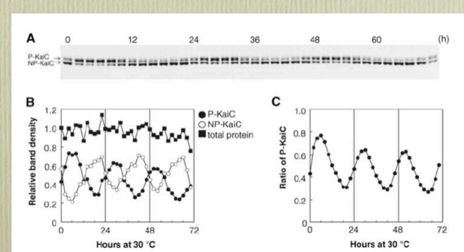
- Many biological processes require a coordinated sequence of events These events are repeated with a well defined period



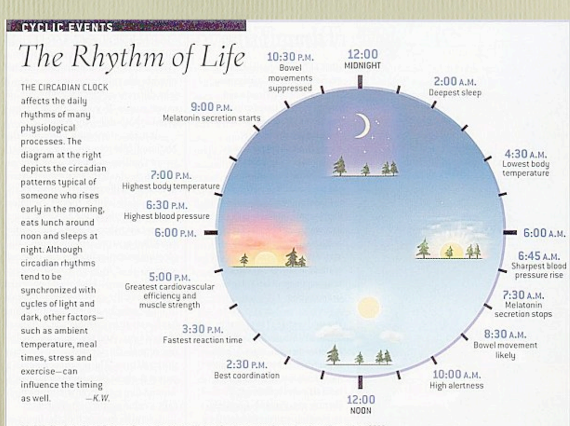

## Biological Clocks

Circadian rhythms are controlled by biochemical networks

- Even bacteria need to keep time: e.g CyanoBacteria
- Eldon Emberley, SFU, finds 3 proteins give an oscillatory system with 24 hour period




## Humans




- Natural cycle ~ 24 hours 11 minutes (average) but wide variations.
- Gets reset ("phase-locked") by light
- Mostly in hypothalamus: suprachiasmatic nucleus, but requires most of endocrine system to work
- Universal in mammals: mechanism can vary, and disappear in arctic animals

- As to moral courage, I have very rarely met with the two o'clock in the morning kind. I mean unprepared courage, that which is necessary on an unexpected occasion. (Napoleon)

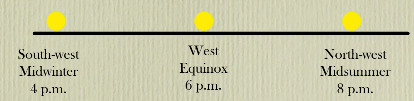
# The first human time-keeper (or the earliest we know about)

- Midsummer day: when the sun rises/sets in most northerly position.

Measured at Stonehenge: important to define seasons and hence time to plant crops

Probably 2300 BC ± 100 years

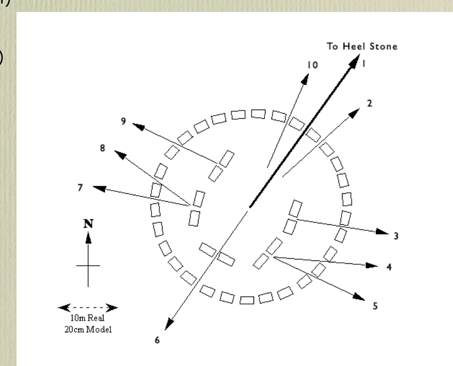
# Sunset




- Note that position varies more as you move away from the equator

- Alignments let you measure summer solstice

1. Midsummer sunrise
2. Winter moonrise low point
3. Midwinter Sunrise
4. Southern moonrise (minimum)
5. Southern moonrise (maximum)
6. Midwinter sunset
7. Northern moonset (minimum)
8. Northern moonset (maximum)
9. Winter moonrise high point




http://www.fas.harvard.edu/~scidemos/AstronomyAstrophysics/Stonehenge/Stonehenge.html

For everything there is a season
And a time for every purpose under heaven:
A time to be born, and a time to die;
A time to plant, and a time to reap;
A time to kill, and a time to heal;
A time to break down, and a time to build up;
A time to weep, and a time to laugh;
A time to mourn, and a time to dance;
A time to throw away stones, and a time to gather stones together;
A time to embrace, and a time to refrain from embracing;
A time to seek, and a time to lose;
A time to keep, and a time to throw away;
A time to tear, and a time to sew;
A time to keep silence, and a time to speak;
A time to love, and a time to hate,
A time for war, and a time for peace.
Ecclesiastes 3:1–8

# Babylon: Mul Apin tablet

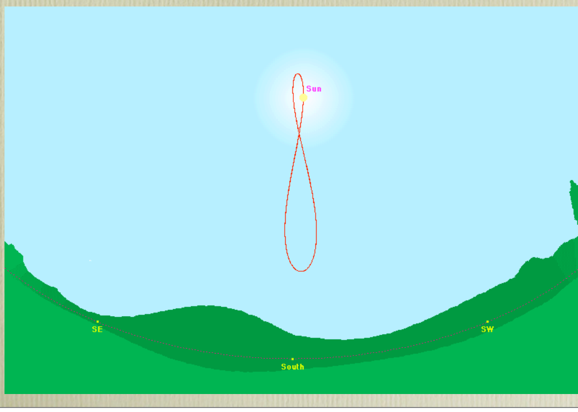
http://www.mesopotamia.co.uk/astronomer/explore/exp_set.html

On the 1st of Nisannu the Hired Man becomes visible.
- On the 20th of Nisannu the Crook becomes visible.
- On the 1st of Ayyaru the Stars become visible.
- On the 20th of Ayyaru the Jaw of the Bull becomes visible.
- On the 10th of Simanu the True Shepherd of Anu and the Great Twins become visible.
- On the 5th of Du'uzu the Little Twins and the Crab become visible.
- On the 15th of Du'uzu the Arrow, the Snake, and the Lion become visble; 4 minas is a daytime watch, 2 minas is a nighttime watch.
- On the 5th of Abu the Bow and the King become visible.
- On the 1st of Ululu [. . . .]
- On the 10th of Ululu the star of Eridu and the Raven become visible.
- On the 15th of Ululu Shu-pa, Enlil, becomes visible.
- On the 25th of Ululu the Furrow becomes visible

# Sundials

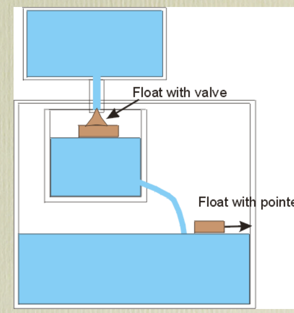
- Good to few minutes but
- ...Position of the noon sun in the sky varies throughout the year:
  - It moves against the fixed stars because
  - the earth orbits the sun
  - the earths axis is tilted

- it also moves in the sky at a given time of day: (i.e. the time of noon varies by about 8 minutes) because the earth moves at varying speeds in its orbit,
- so we actually need a **better** clock than the sun to measure this

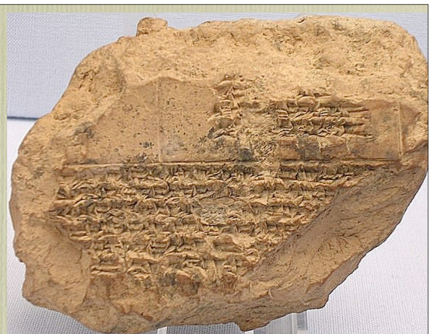



# Water-clock (probably first non-astro clock)

- www.mlahanas.de/ Greeks/Clocks.htm
- Water in a container drains out through small hole: problem is that the flow is non-uniform.
- Hence keep container full with valve so as to have constant pressure
- clepsydra (= "water thief")




# Eclipses



Tablet with a list of eclipses between 518 BC and 465 BC, mentioning the death of king Xerxes.
British Museum, London

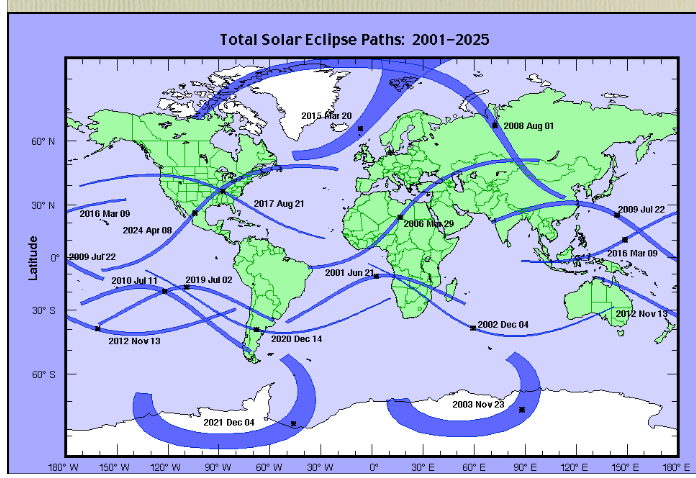
Why do these matter?

CALPURNIA: When beggars die, there are no comets seen;

The heavens themselves blaze forth the death of princes. *Julius Caesar*

(Chinese astronomers Hi and Ho executed for failing to predict eclipse in 2134 BC).

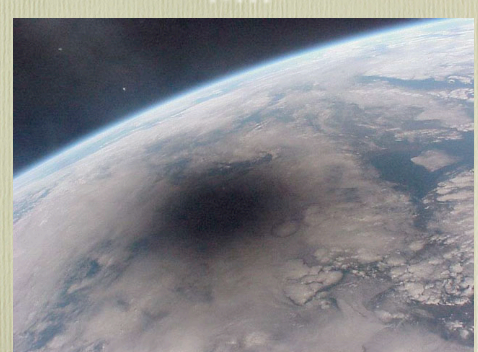
# Eclipse preediction




# Saros cycle

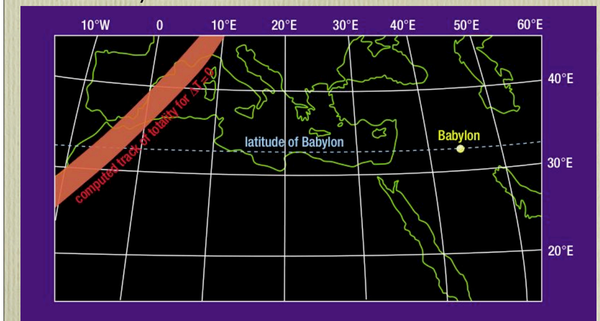
- Eclipses repeat after 18 years and 11.3 days.
- The .3 days shifts the eclipse about 110º degrees west.
- Also some saros sequences start at the south and drift North, others at the North and drift South.
- This means that the cycle is very complex: can only see it after many years.
- Why is it so complicated? Need to combine
  I. Earths rotation
  II. Moons orbit (not quite circular)
  III. Earth's orbit (ditto)
  IV. <u>and</u> the plane of the moons orbit precesses

# Eclipse of 1999 seen from Mir



[Observed total Eclipse 15 April 136 BC.]

- and they would even have seen it [from the moon !]
- But they shouldn't have!




4: Computed track of totality for the eclipse of 15 April in 136 BC, assuming a fixed length of day ($\Delta T = 0$). This track lies more than 50° to the west of Babylon, where totality was actually observed.

- Earth's rotation has slowed down, by 1/100 sec/century, because of tidal effects! i.e. earth isn't a very good time-keeper

# Pendulum Clock

Invented by Huyghens (1656)
Look at the Foucault pendulum in the entrance to Herzberg building: [Watch the animation.]

- Period:

$$P = 2\pi\sqrt{\frac{L}{g}}$$

- So 1 metre simple pendulum should have period of ~1s?
- Accuracy ~ 1 minute/day

# Chronometer

Longitude problem: error on longitude typically 100 km (!) in 18th century. Admiralty offered £20,000 ($10,000,000 today) to solve problem

- Need to determine time to better than 1 s/day
- Harrison (1721) constructed chronometer accurate to better than 1/5 s/

## Note that this depends on mechanical escapement

Photo Suat mEan FreeDigitalPhotos.net

A doctor's watch c 1815

## Any sufficiently advanced technology is indistinguishable from magic (Arthur Clarke)

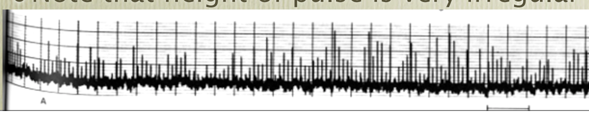
My watch (c 2009)

# What's the difference?

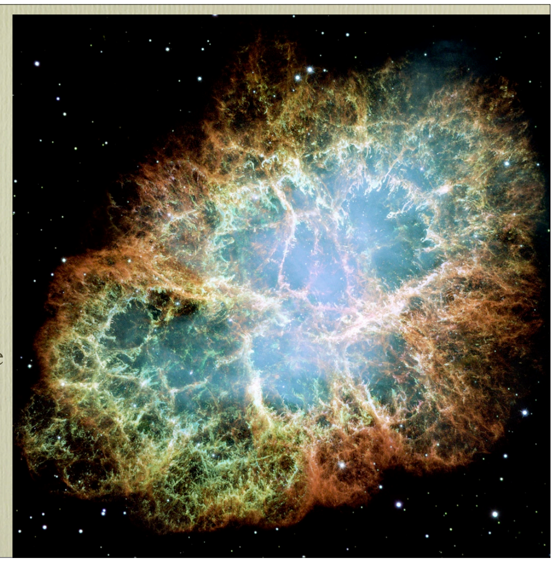
- **Power Source:** Coiled spring
- Mercury Battery
- **Time:** escapement mechanism
- Quartz crystal
- **Displays:** second hand + date wheel
- LCD
- **Setting:** listen to the church clock!
- Reset once a day by transmitter in Colorado

# Pulsars (1968)

- neither earth's orbit or rotation are sufficiently stable now: best astronomical timekeeper are pulsars, accidentally observed as pulsars (Jocelyn Bell etc)
- Very regular radio pulses,period of 4 s to 2 ms
- Note that height of pulse is very irregular



Best known is Crab. Known to be remnant from supernova in 1054 (seen by Chinese) Pulsar at centre has period of ~0.03s



# And you can even listen to them

This is Vela

And this is PSR 0329+54

Period of Crab measured to be 0.03308471603 s (i.e. stable to 1 part in billion)

# Frequency and Period

Note for what follows:

- for repeated motions (e.g. Oscillators), Time and frequency are closely linked
- Frequency = 1/Period
- So something that vibrates with a period of 0.5 s has a frequency of 2 Hertz (2 Hz)

$$F = \frac{1}{P}$$

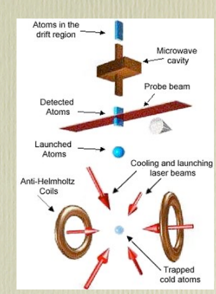
# Units

| Unit | Abbreviation | Defined by |
|---|---|---|
| 1 metre | 1 m | 1/40,000,000 th of circumference of the earth |
| 1 second | 1 s | 1/84,600 th of mean solar day |
| 1 kilogram | 1 kg | Mass of lump of platinum in Paris |

- But........... This leads to more problems: circumference of earth differs at various places,....rotation speed of earth varies...
- Need **reproducible unit**, so any lab can measure it
- Define time via the oscillations of a caesium atom
- 1 s = 9,192,631,770 f
- Distance used to be via wavelength of red line from $Kr^{86}$ light ( 1 m = 1,650,763.73 l)
- but now speed of light (c) is much better measured, so
- 1 m = distance travelled by light in 1/299,792,458 s

# Atomic Clocks

- Best is now at NRC: Caesium fountain clock better to 1 part in $10^{12}$ i.e. would lose or gain ~ hour over lifetime of universe: so accurate that the only comparison is one Cs clock to another!
- Works because atoms are isolated from each other, so don' influence each other
- Target is 1 part in $10^{15}$: one minute in lifetime of universe



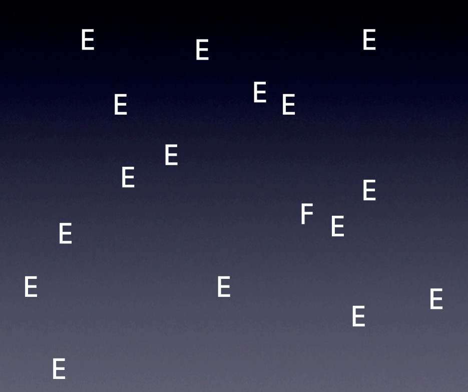
# Subdivisions of time: Direct perception

- Roughly 1/10s = 100 ms, but depends very much on the stimulus
- E.g. Some slides stolen from Marcus Watson

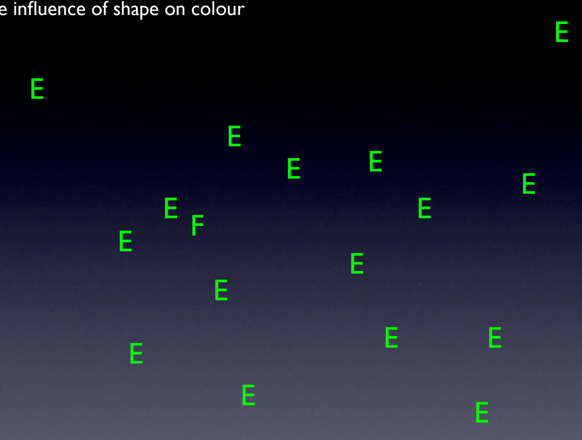
The influence of shape on colour

Find the "F"

The influence of shape on colour

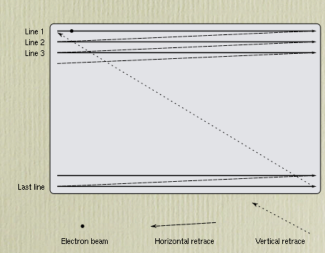


The influence of shape on colour



The influence of shape on colour

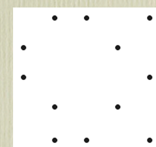
# Limits:

- Eyes can't respond in much less than 1/20 s (= 50ms)
- Which is why we can watch TV
- 

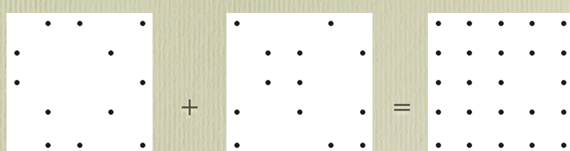
# Picture as seen

- But shoot it too fast

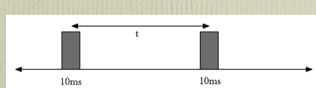
Brain will actually superimpose pictures if time is very short



# Analyzing




If the gap t < 100 ms, see one image and can pick out missing spot
If the gap t > 100 ms, see two images, cannot pick out missing spot




# Indirect perception via sounds

- We can hear notes in octaves: each octave is a doubling of frequency

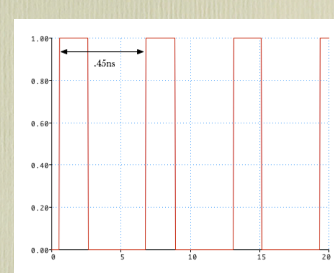
- C Db D Eb E F Gb G Ab A Bb B

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C | 8.2 | 16.4 | 32.7 | 65.4 | 130.8 | 261.6 | 523.3 | 1046.5 | 2093.0 | 4186.0 | 8372.0 |
| Db | 8.7 | 17.3 | 34.6 | 69.3 | 138.6 | 277.2 | 554.4 | 1108.7 | 2217.5 | 4434.9 | 8869.8 |
| D | 9.2 | 18.4 | 36.7 | 73.4 | 146.8 | 293.7 | 587.3 | 1174.7 | 2349.3 | 4698.6 | 9397.3 |
| Eb | 9.7 | 19.4 | 38.9 | 77.8 | 155.6 | 311.1 | 622.3 | 1244.5 | 2489.0 | 4978.0 | 9956.1 |
| E | 10.3 | 20.6 | 41.2 | 82.4 | 164.8 | 329.6 | 659.3 | 1318.5 | 2637.0 | 5274.0 | 10548.1 |
| F | 10.9 | 21.8 | 43.7 | 87.3 | 174.6 | 349.2 | 698.5 | 1396.9 | 2793.8 | 5587.7 | 11175.3 |
| Gb | 11.6 | 23.1 | 46.2 | 92.5 | 185.0 | 370.0 | 740.0 | 1480.0 | 2960.0 | 5919.9 | 11839.8 |
| G | 12.2 | 24.5 | 49.0 | 98.0 | 196.0 | 392.0 | 784.0 | 1568.0 | 3136.0 | 6271.9 | 12543.9 |
| Ab | 13.0 | 26.0 | 51.9 | 103.8 | 207.7 | 415.3 | 830.6 | 1661.2 | 3322.4 | 6644.9 | 13289.8 |
| A | 13.8 | 27.5 | 55.0 | 110.0 | 220.0 | 440.0 | 880.0 | 1760.0 | 3520.0 | 7040.0 | 14080.0 |
| Bb | 14.6 | 29.1 | 58.3 | 116.5 | 233.1 | 466.2 | 932.3 | 1864.7 | 3729.3 | 7458.6 | 14917.2 |
| B | 15.4 | 30.9 | 61.7 | 123.5 | 246.9 | 493.9 | 987.8 | 1975.5 | 3951.1 | 7902.1 | 15804.3 |

- Roughly 20 Hz to 20 kHz
- O.K. 10 kHz for us!
- I.e. 50 ms down to 0.05 ms=50μs
- (why have we bothered to evolve this?)

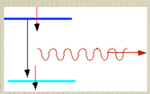
# Electronics Directly

- Clock circuit in computer
- 2.8 GHz in this Mac:
- i.e. ~.35 nanoseconds (ns)



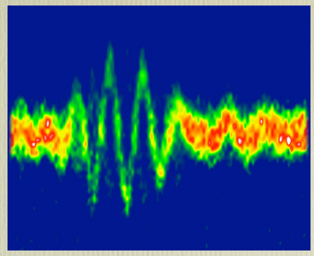
# Atomic transitions

- E.g the laser pointer
- Atom makes transition from one level to another, emitting photon
- Typical time ~ 1 picosecond (ps)=$10^{-12}$ s = 1/trillionth second=0.000000000001s



# Pulsed lasers

- Paul Corkum at NRC/Ottawa U developed techniques for cutting laser beams in few atto-second lengths:
- 1 attosecond (as) =$10^{-18}$ s =0.000000000000000001s
- Allows still pictures of atoms



# Particle Physics

- Reactions occur roughly at speed of light over the size of a proton
- Typical time ~ $10^{-24}$ s = 1/trillion-trillionth second =0.000000000000000000000001s
- 1 yoctosecond, except no-one ever calls it that

# Planck time

- *If* we believe in superstring theory, they oscillate with a period
- $$t_p = \left(\frac{G\hbar}{c^5}\right)^{1/2} = 5.4\times 10^{-44} s$$
- 0. 00000 00000 00000 00000 00000 00000 00000 00000 00005s
- Shortest time scale that makes any sense in physics

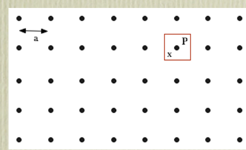
# But wait a moment

- Can we really go on subdividing time?
- Is it really continuous or a succession of moments?
- Like a water-wave?

- Magnify by 1000: OK
- Magnify by 1000000: OK
- Magnify by 1000000000: start seeing molecules

# Is time continuous?

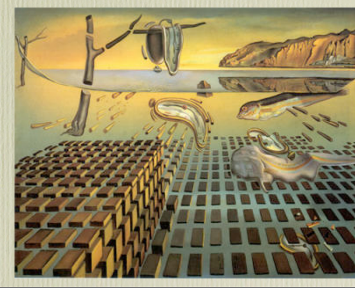
- Is space?
- Suppose space is discrete at some scale a: say 1 attometre (1/1000 size of a proton)
- Then sizes smaller than this have no meaning




- How Dali changed "the Persistence of Memory

into

- "The Disintegration of the Persistence of Memory"



# Is time continuous?

- Hence time scales shorter then $a/c \sim 10^{-27}$ s have no meaning
- Which is roughly the kind of limit we have now
- If space or time is quantized in some way, the reality is probably much more complicated

# How about large time intervals?

- Much less interesting
- Human lifetime ~ $2\text{x}10^9$s = 2 Gigasecond = 2Gs ~88 years
- Lifetime of the universe ~ $5\text{x}10^{17}$s = 0.5 exasecond = .5 Es ~14 billion years
- SO we can measure time to fantastic accuracy: can we even understand why there is a past and a future?