....and finally

Does time really pass faster as we get older ?

Come to the next lecture on 25th March 2004

Turning back the hands of time:
growing old gracefully

Biological clocks:
human and animal concepts of time

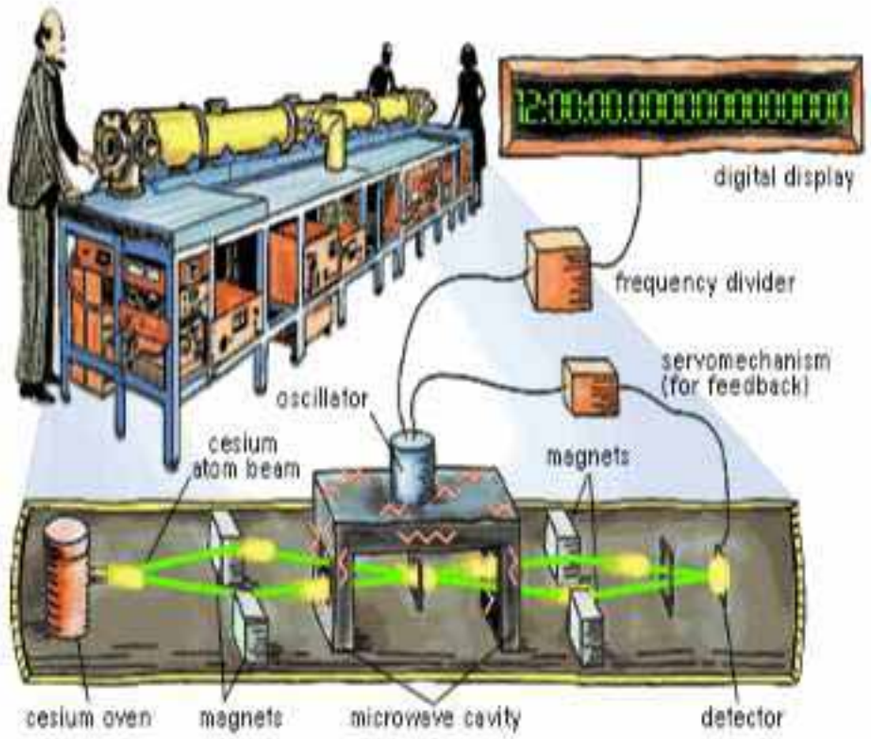
Professor Keith Kendrick

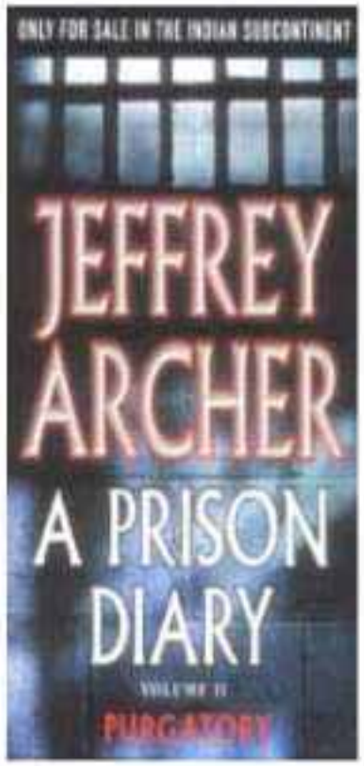
The fourth dimension

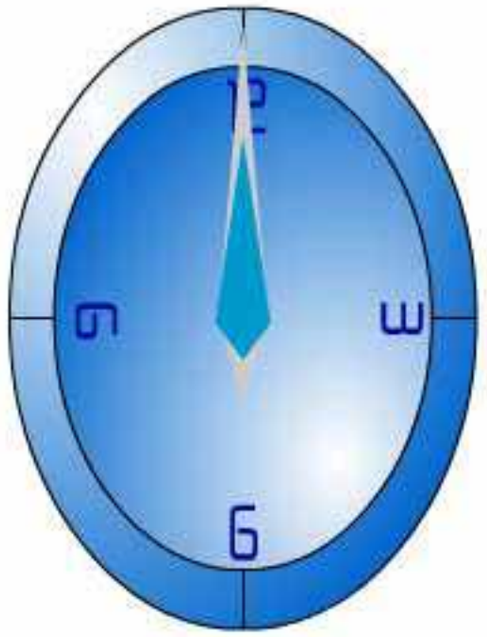
We surround ourselves with keepers of the fourth dimension:

The fourth dimension

We surround ourselves with keepers of the fourth dimension: TIME

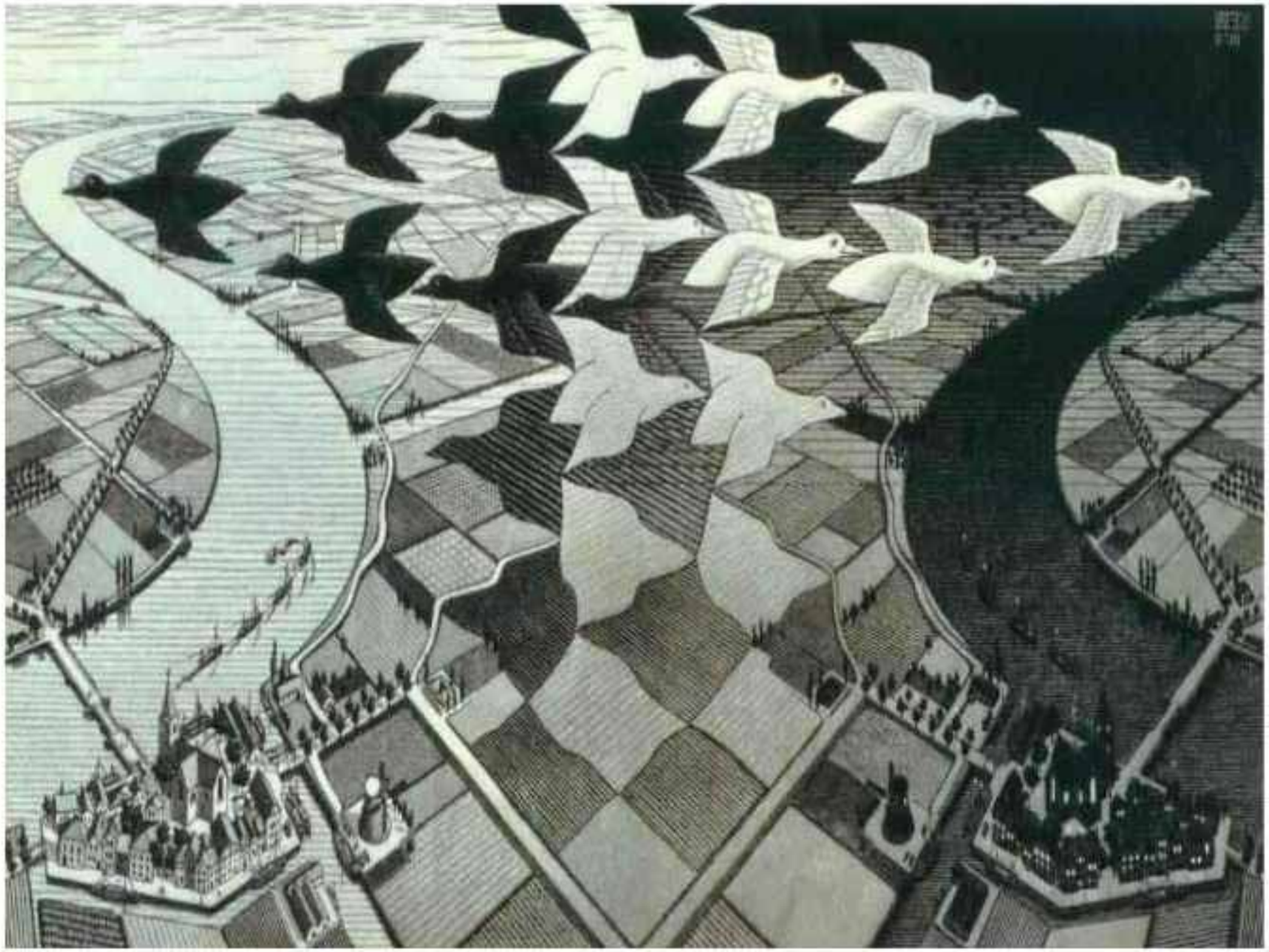




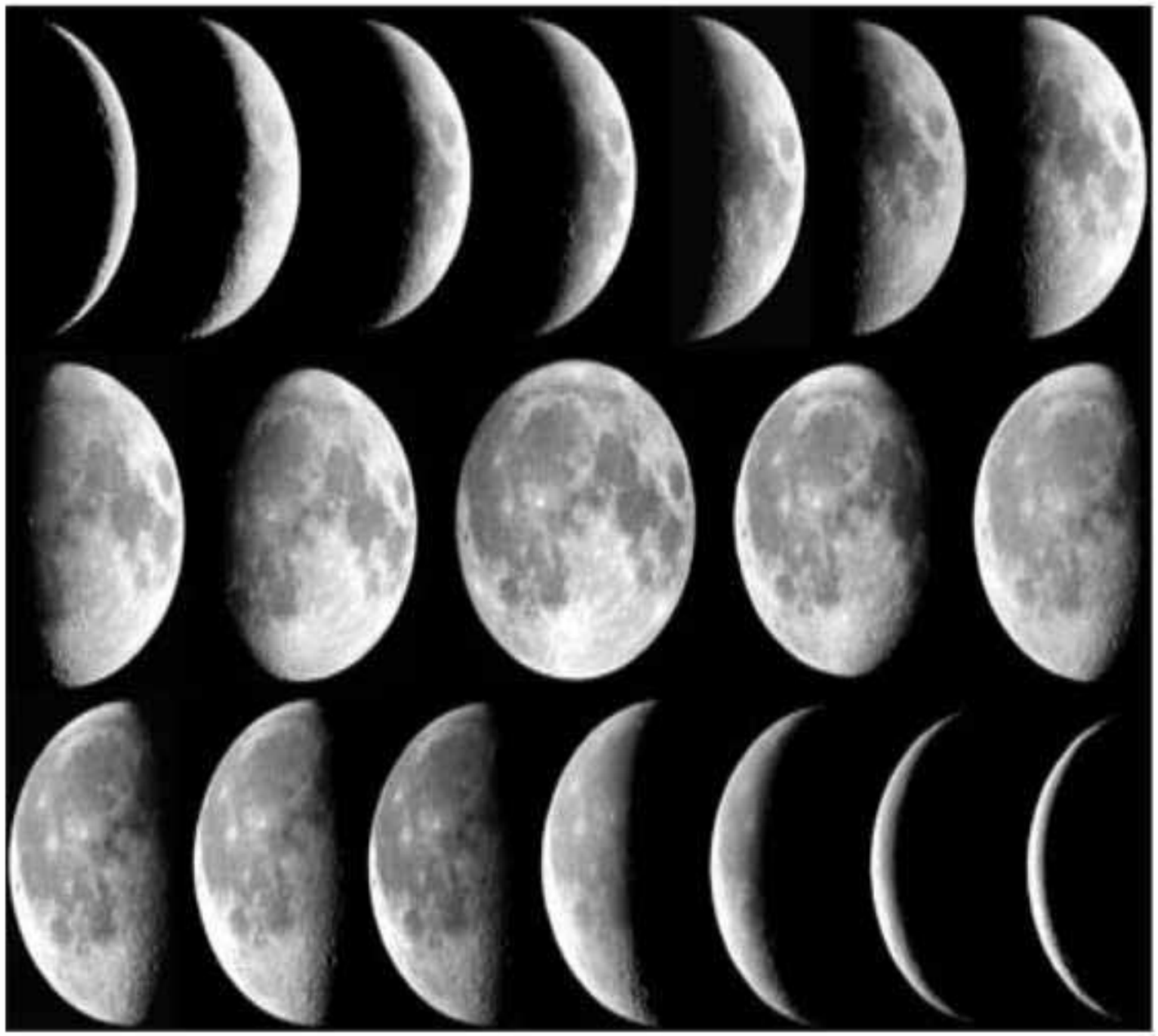


The natural world also keeps time for us

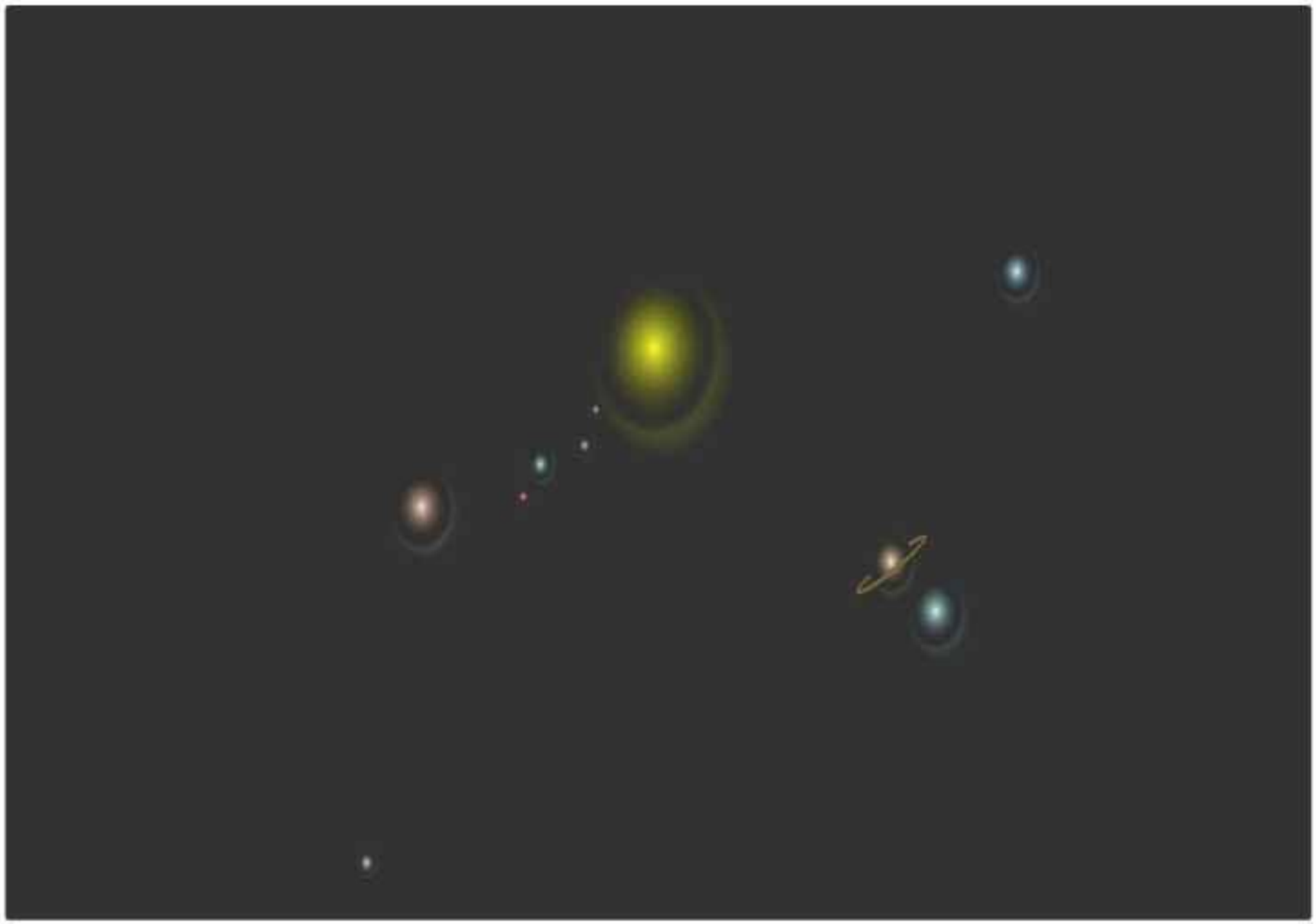
The natural world also keeps time for us



The natural world also keeps time for us

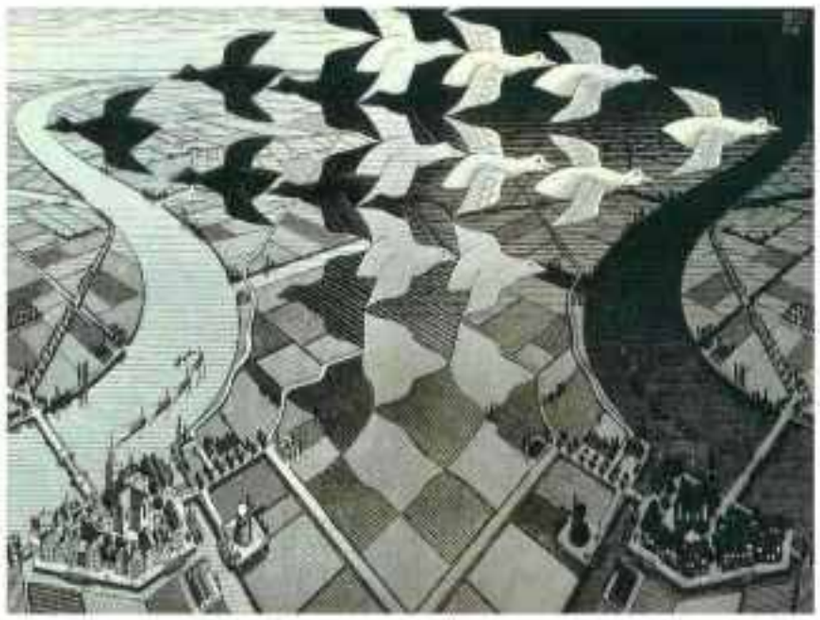


The natural world also keeps time for us



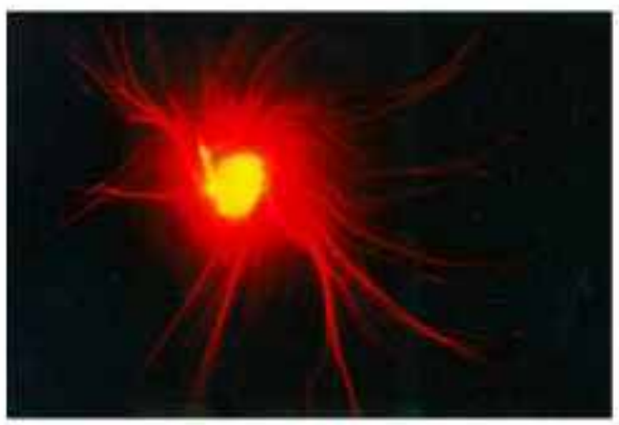
Question: With all these external zeitgebers (time-givers) is there any need for biological clocks ?

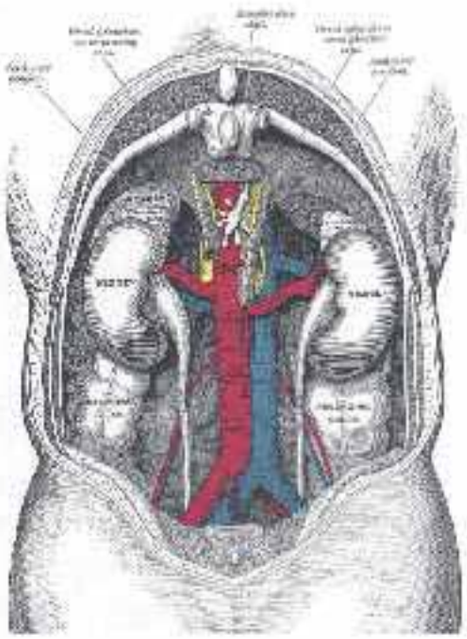
Answer: Yes



Question: With all these external zeitgebers (time-givers) is there any need for biological clocks ?

Answer: Yes, all biological organisms from single cells to whole organs from plants to animals, including humans, have them

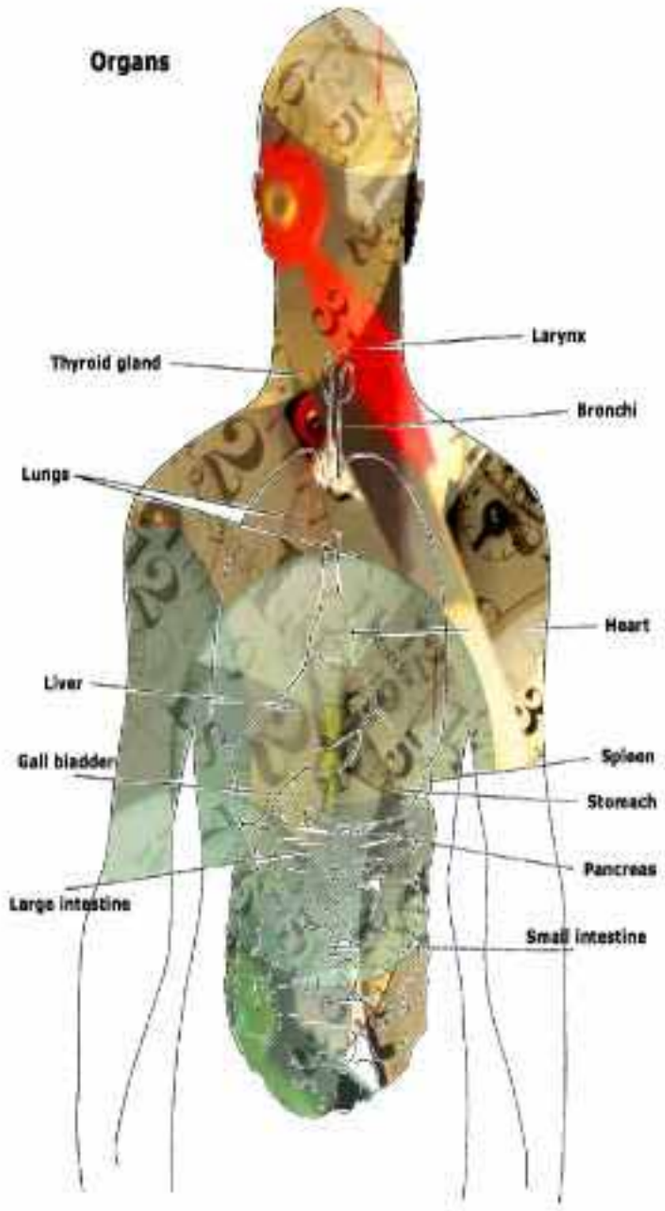




Our bodies resemble the classic nightmare shop full of ticking and chiming clocks which are only stopped by death

The natural world

Our bodies resemble the classic nightmare shop full of ticking and chiming clocks which are only stopped by death

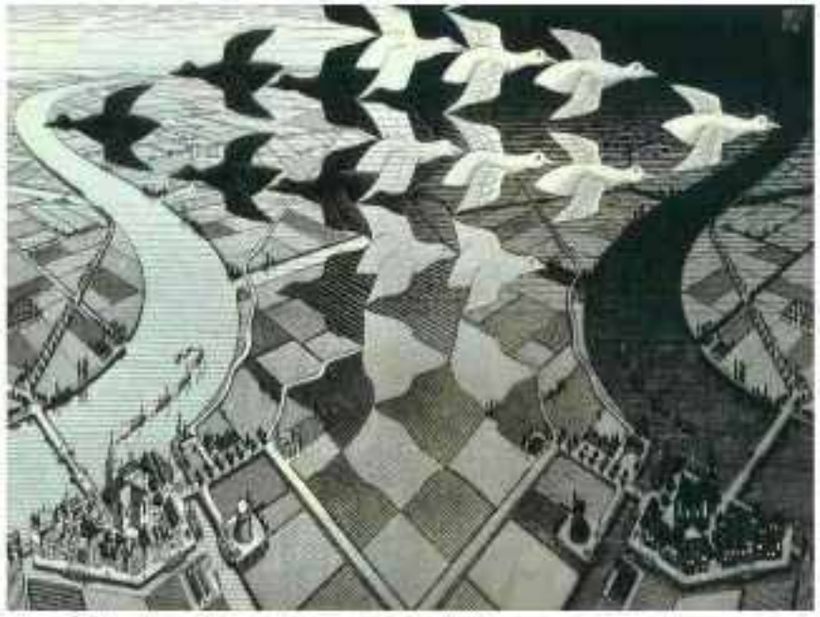


Biological clocks are fuelled by the energy we derive from food

The natural world

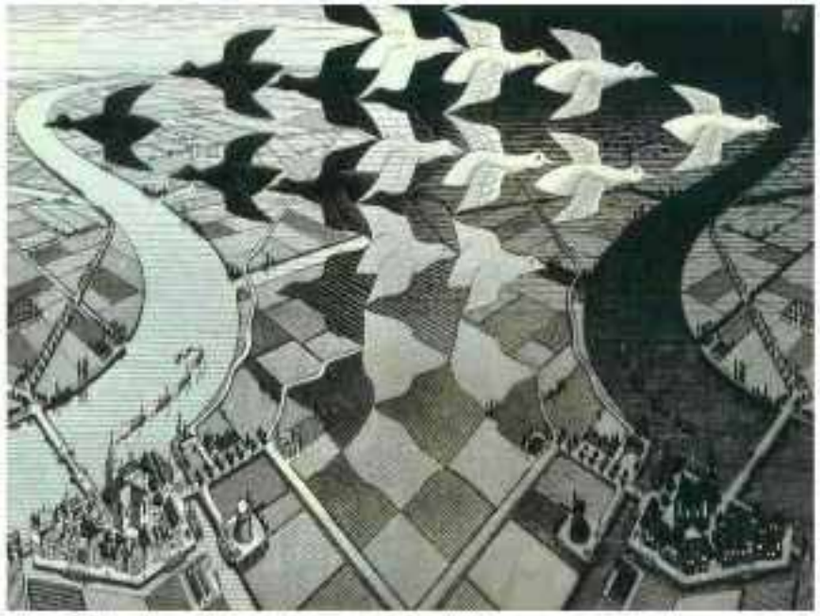
Biological clocks are fuelled by the energy we derive from food

They rely on external zeitgebers to keep them in phase with nature



The natural world

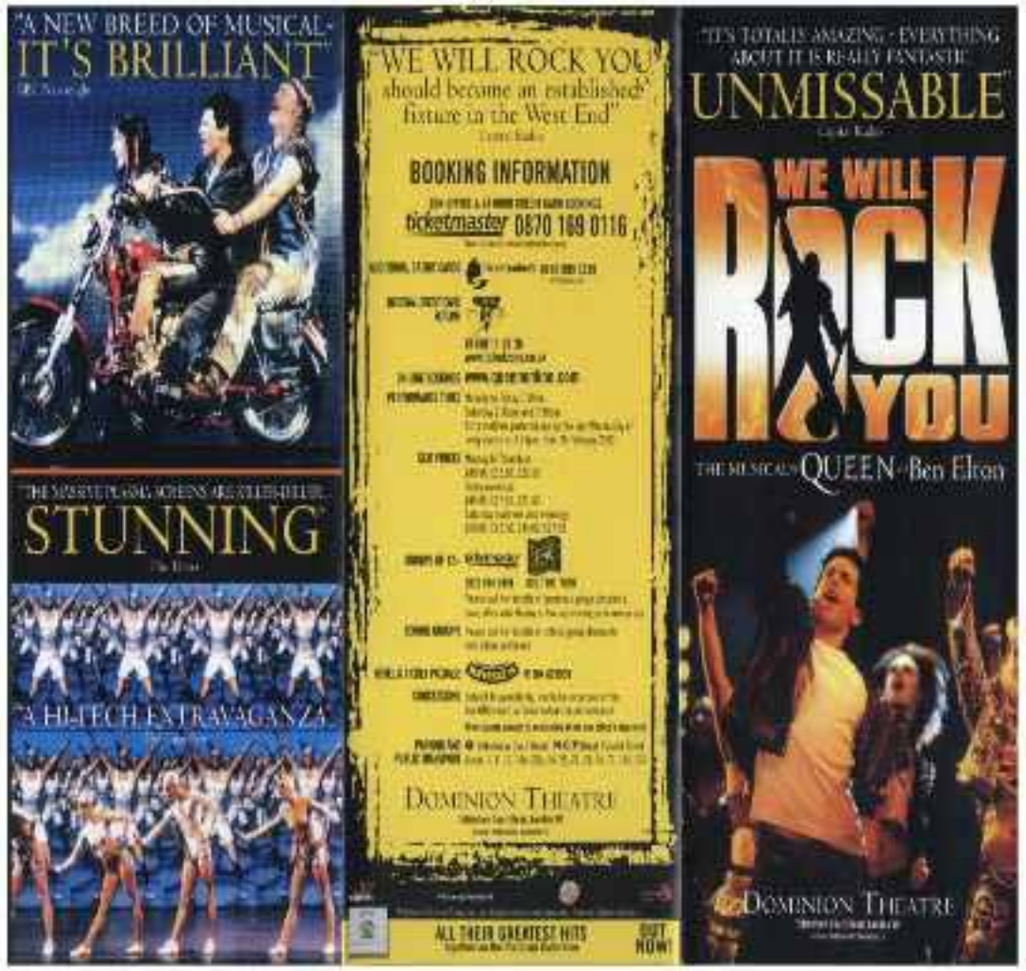
We don't just dance to the rhythms of the world around us



The natural world

We don't just dance to the rhythms of the world around us

We dance to our own tunes but in harmony with the rhythms going on around us



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The bad news is time flies -

The natural world

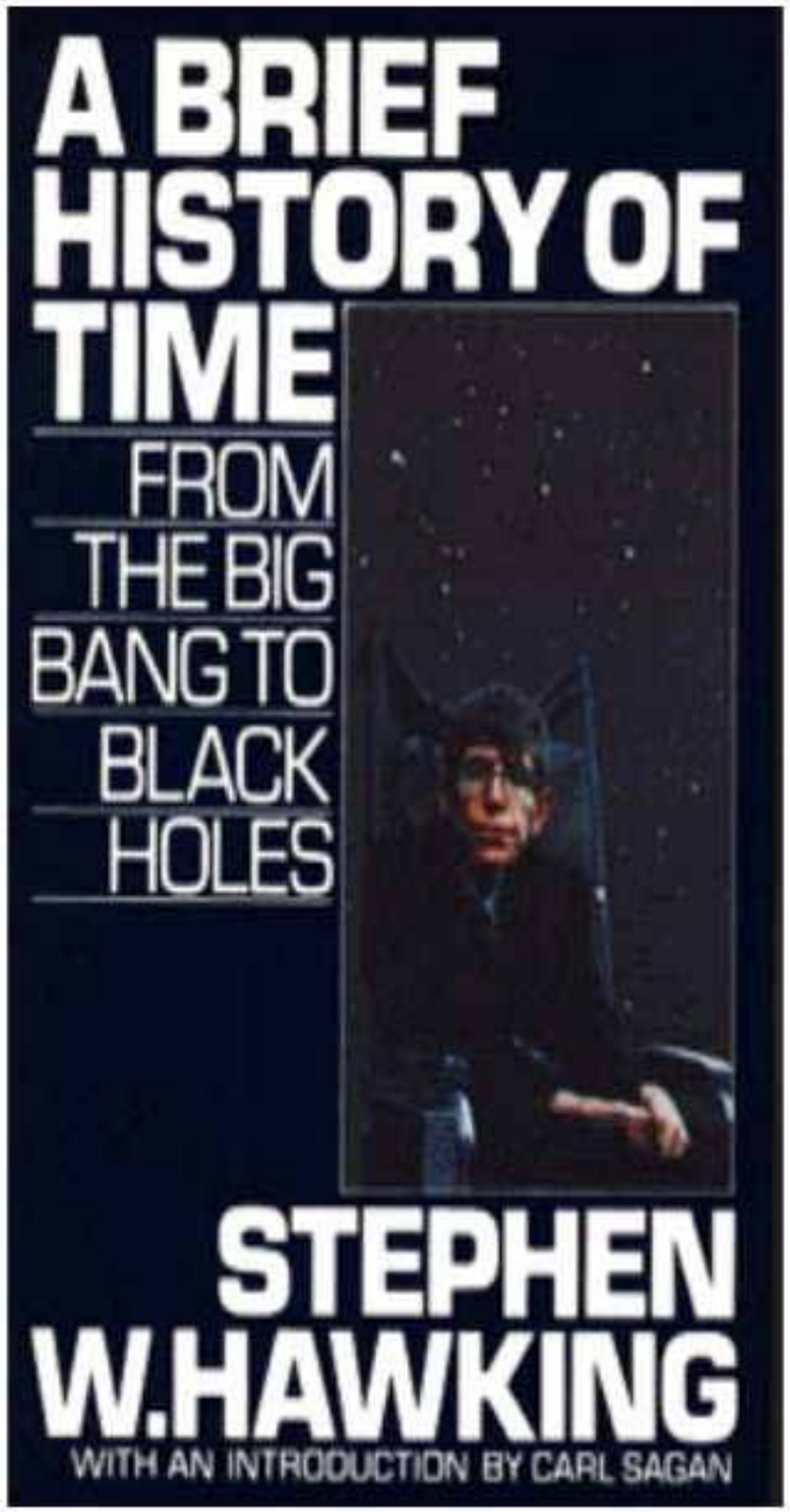
We don't just dance to the rhythms of the world around us

We dance to our own tunes but in harmony with the rhythms going on around us

The bad news is time flies -
The good news is you're the pilot
(Michael Althsuler)

Why do we need to know about them ?

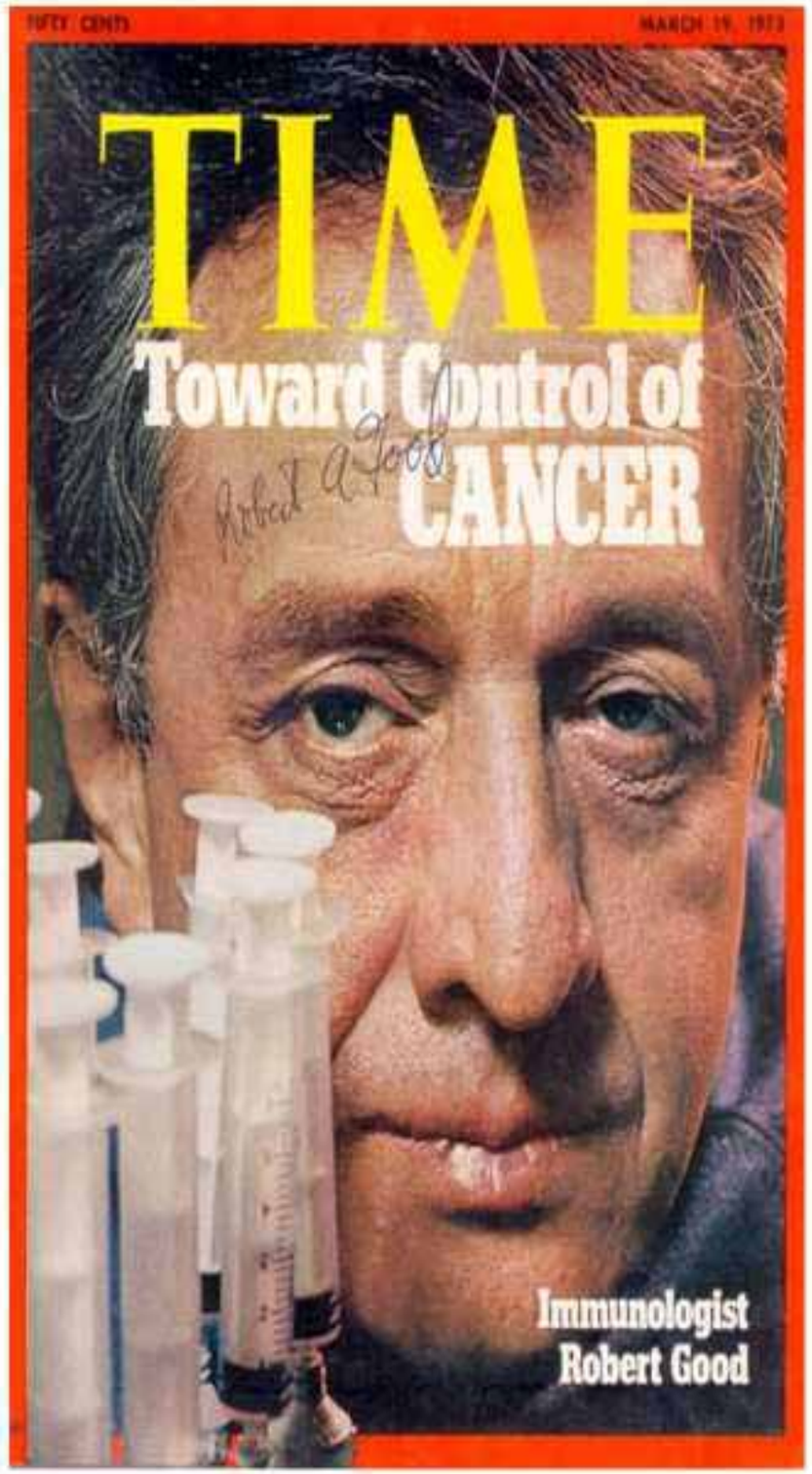
Understanding dimensional and cosmological time may reveal how to travel in time and the origins of the universe



Why do we need to know about them ?

Understanding dimensional and cosmological time may reveal how to travel in time and the origins of the universe

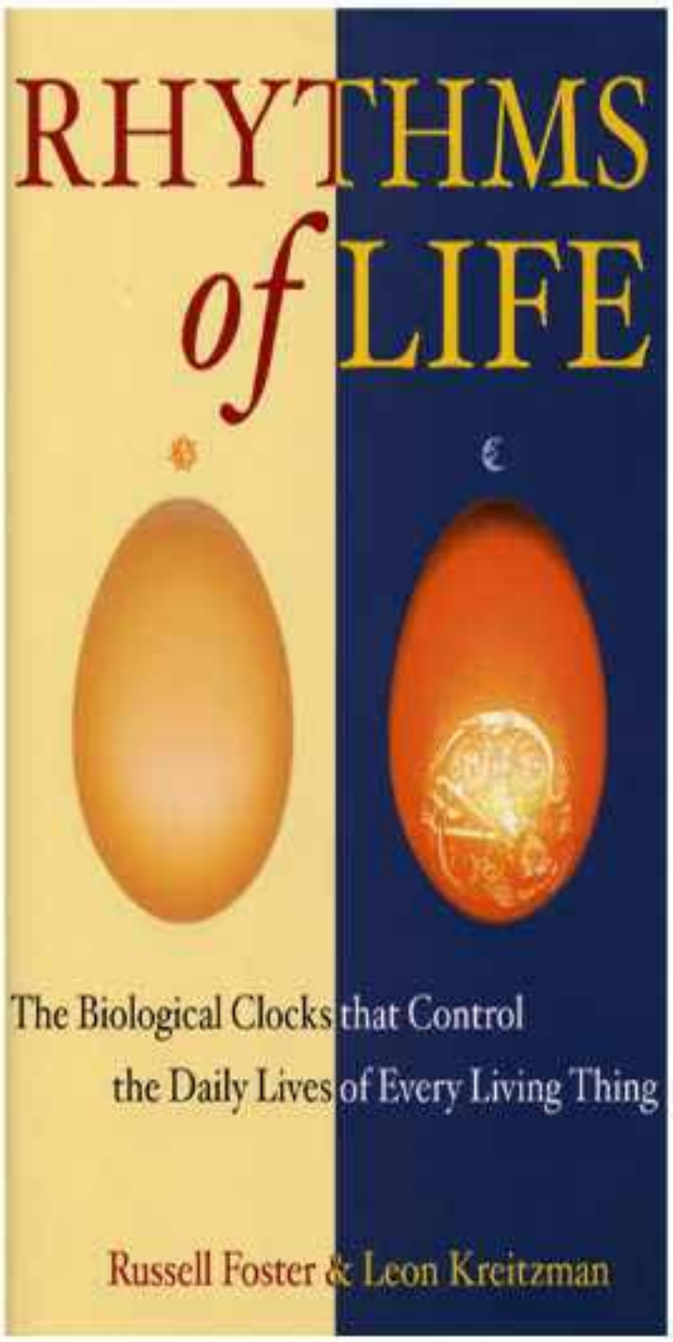
Understanding biological time will reveal not only how our bodies function but also how to treat or prevent major human diseases



A brief history of time in a biological context

Rhythms of Life

Foster and Kreitzman (2004)



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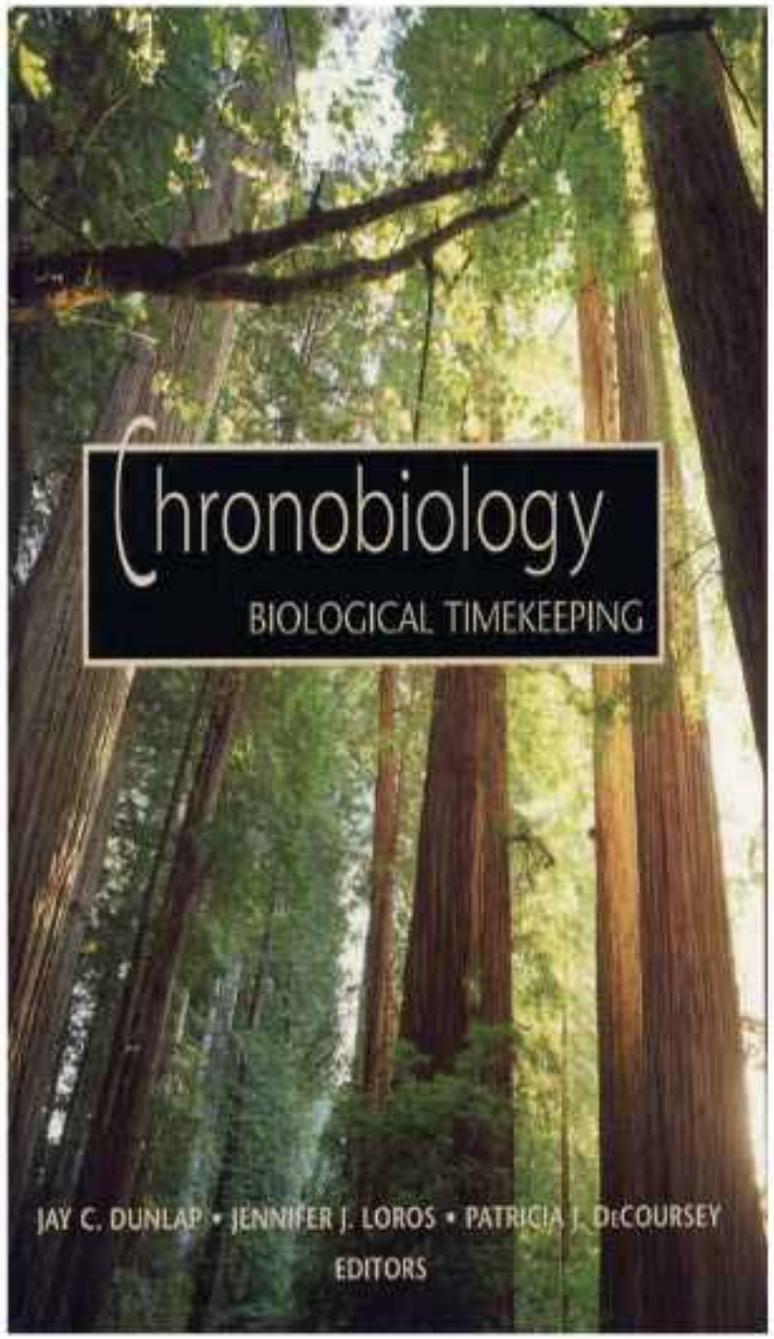

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Mimosa plants

de Mairan (1729)

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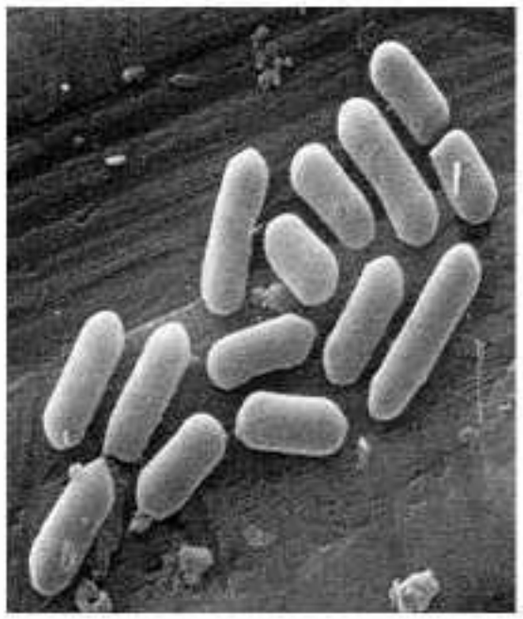
Mimosa plants
de Mairan (1729)

The common bean plant
Erwin Bünning (1930)

A brief history of time in a biological context

Numerous internally regulated biological rhythms have now been established in both plant and animal kingdoms



A brief history of time in a biological context

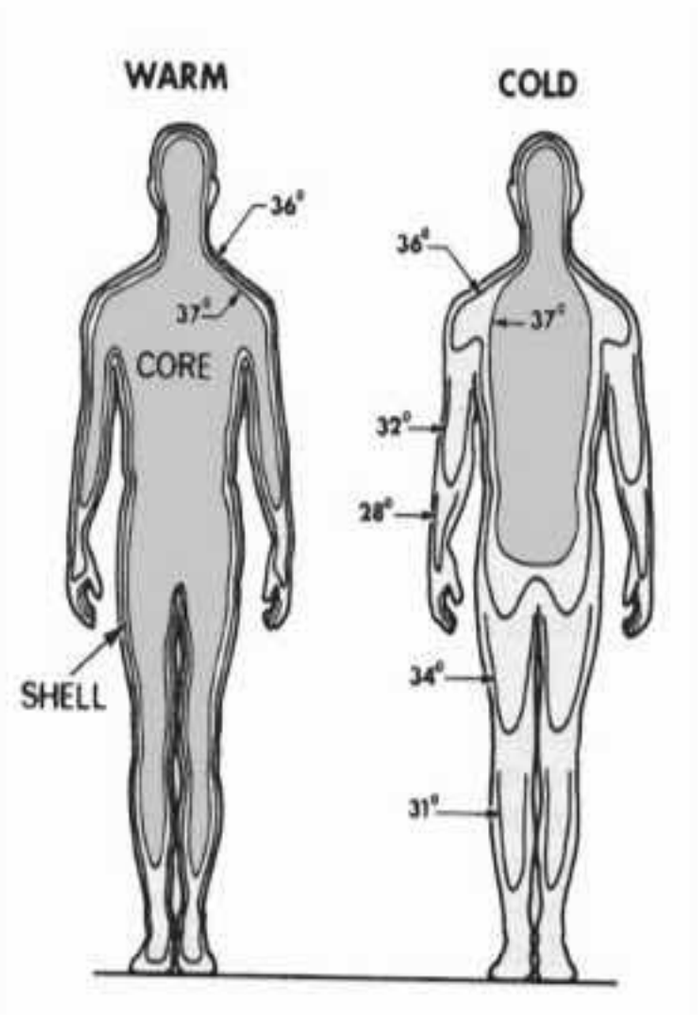
Biological clocks are quite accurate (usually about ±0.5%)

Linné (1751)

A brief history of time in a biological context

Biological clocks are quite accurate (usually about ±0.5%)

They have in-built temperature compensation



A brief history of time in a biological context

Biological clocks are quite accurate (usually about ±0.5%)

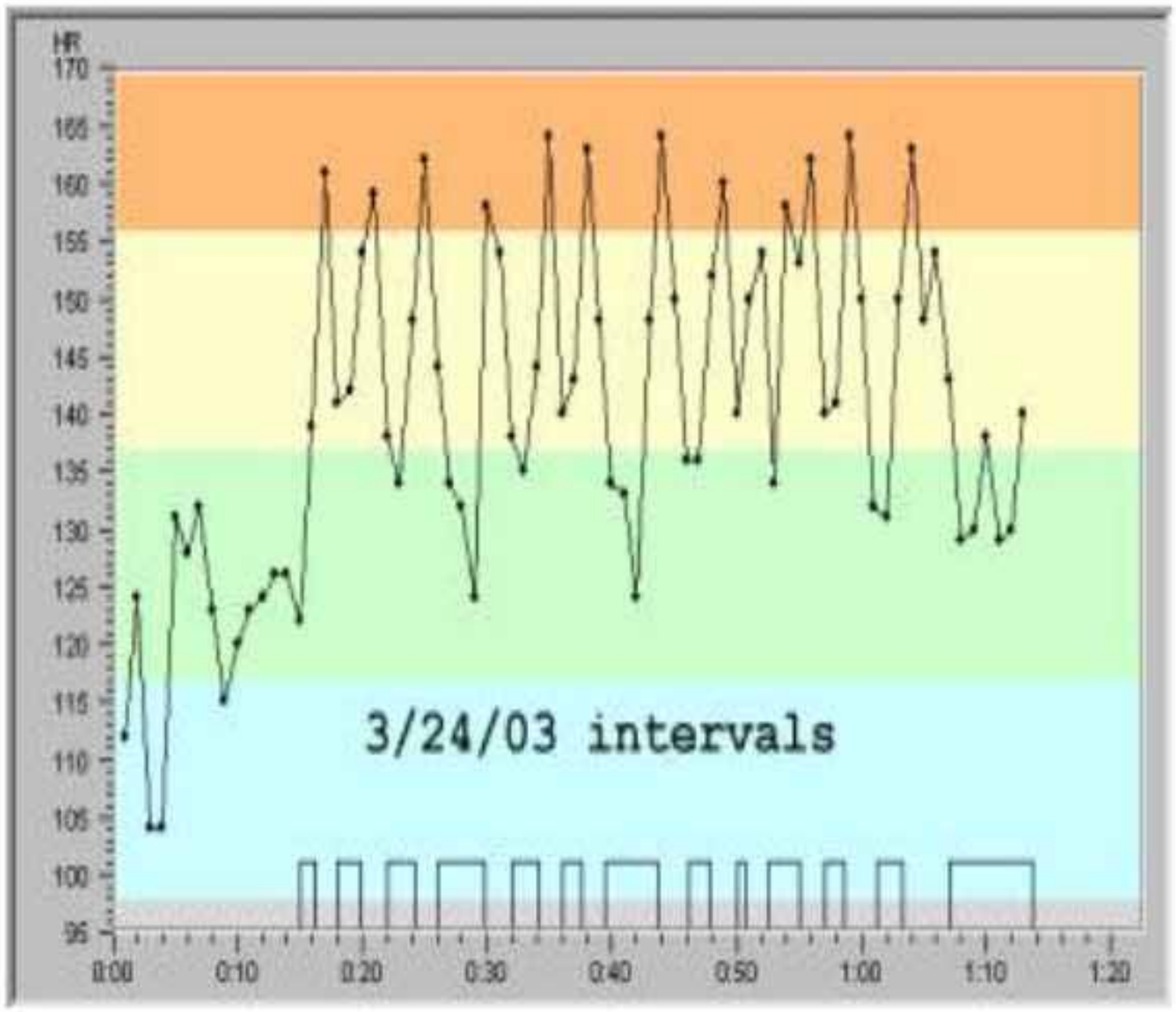
They have in-built temperature compensation

In many cases these can be entrained in response to external light cues

Some can also be entrained in response to food

Examples of innate rhythms

All organisms have ultradian cycles (<24h)

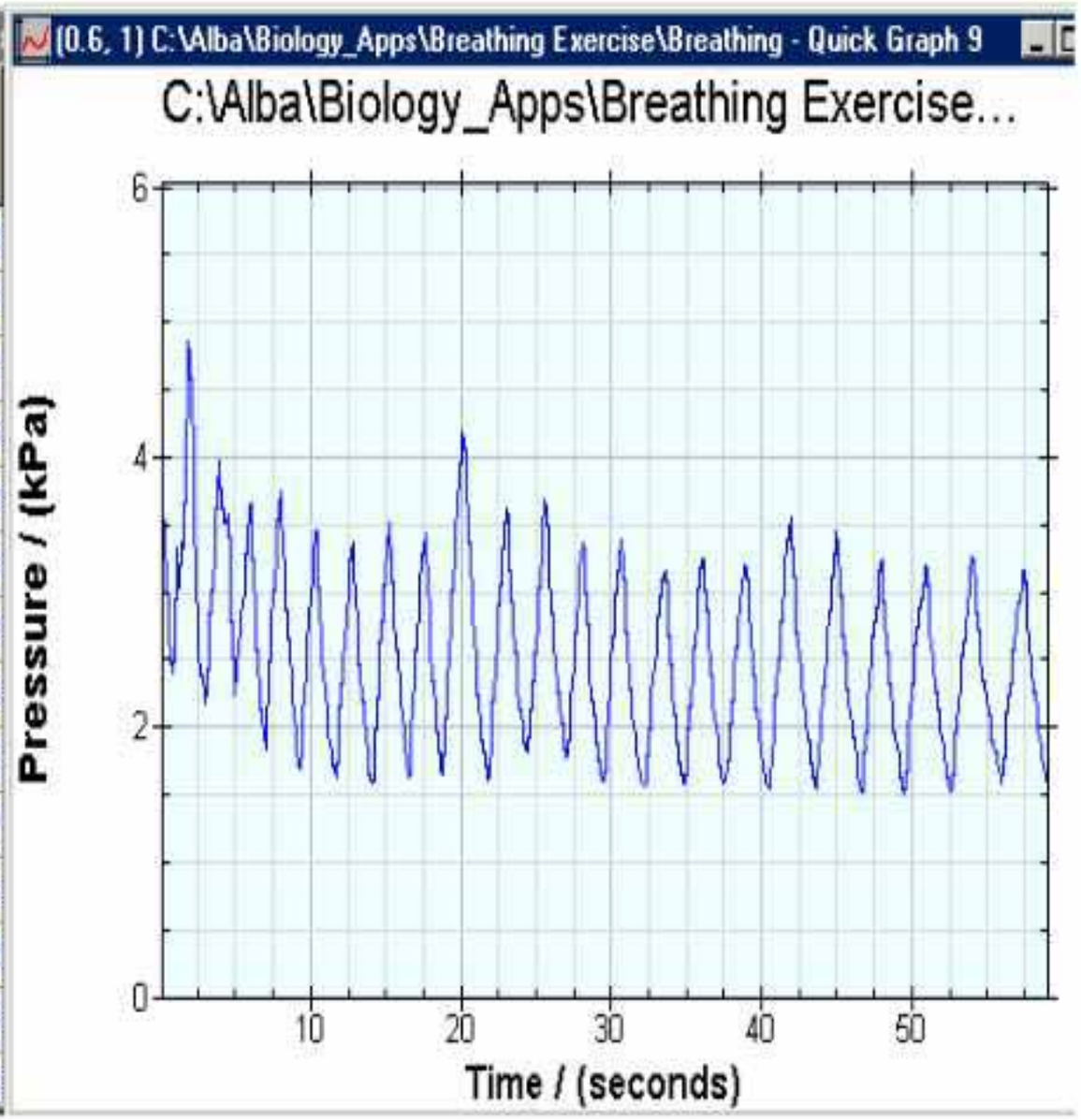


Examples of innate rhythms

All organisms have ultradian cycles (<24h)

C:\Alba\Biology_Apps\Breathing E

notes	Time seconds t	Pressure kPa P
1	0.0	3
2	0.1	4
3	0.2	4
4	0.3	3
5	0.4	3
6	0.5	3
7	0.6	3
8	0.7	3
9	0.8	2
10	0.9	2
11	1.0	3
12	1.1	3
13	1.2	3
14	1.3	3



Examples of innate rhythms

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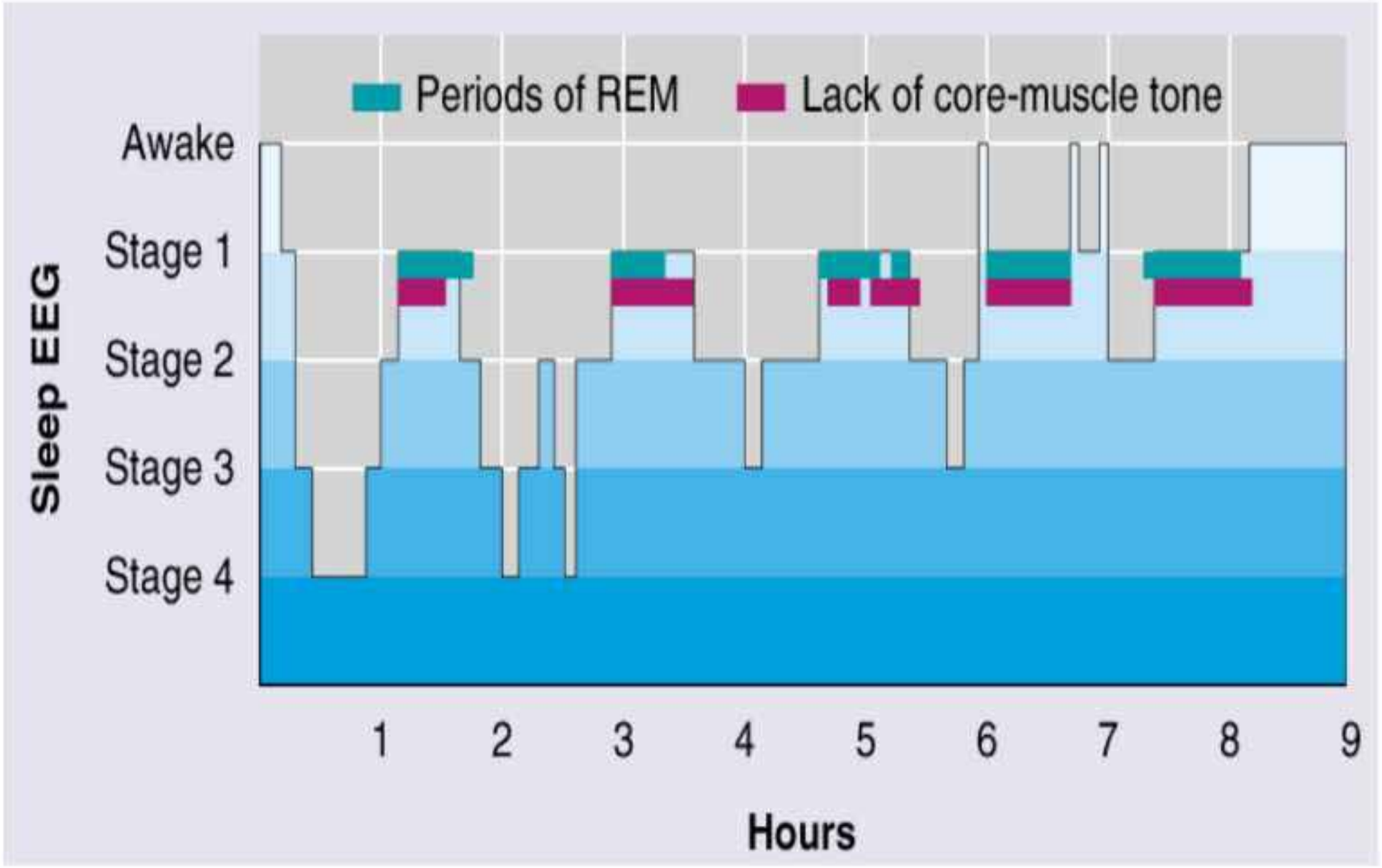
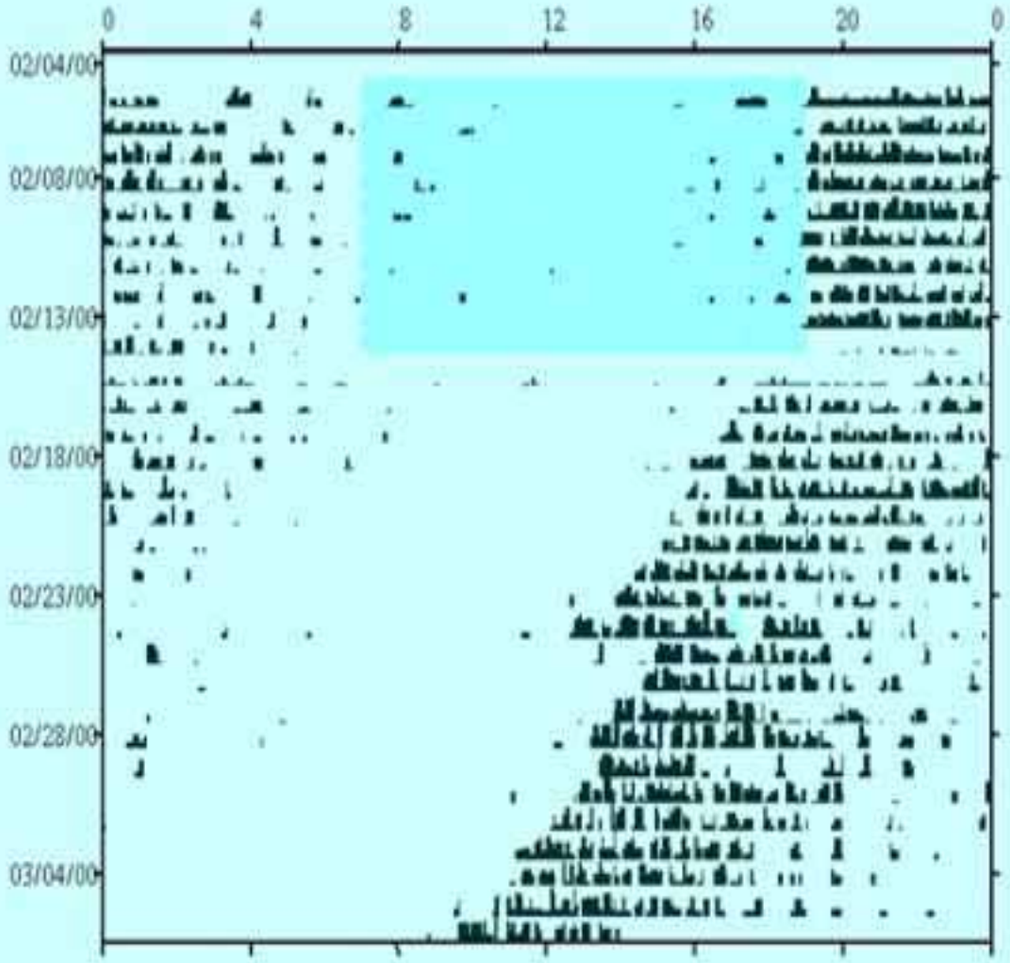


Examples of innate rhythms

All organisms exhibit circadian rhythms (24h)

Wheel-running activity in mice



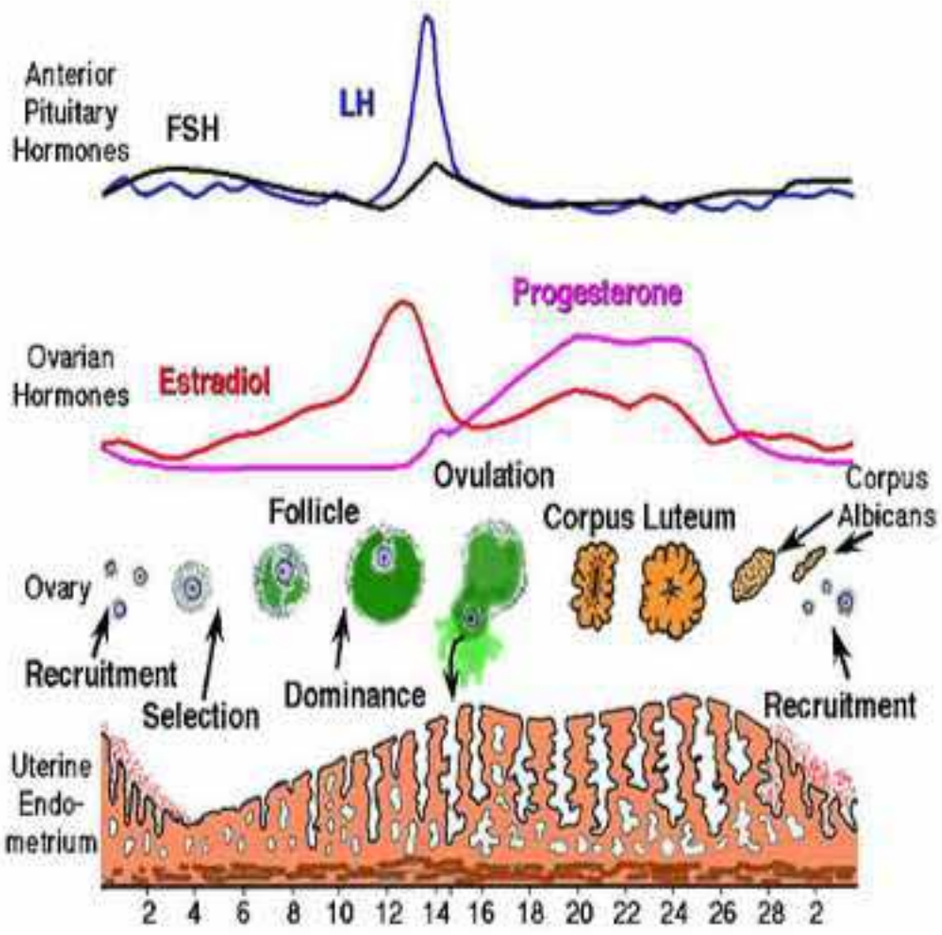
In a 12:12 light:dark cycle, onset of activity in mice is coincident with 'lights off'.

In the absence of external stimuli, activity onsets are set by the central pacemaker (SCN)

Brief light pulses at distinct phases of the activity cycle can shift the activity onset

Examples of innate rhythms

Many have infradian cycles (>24h)

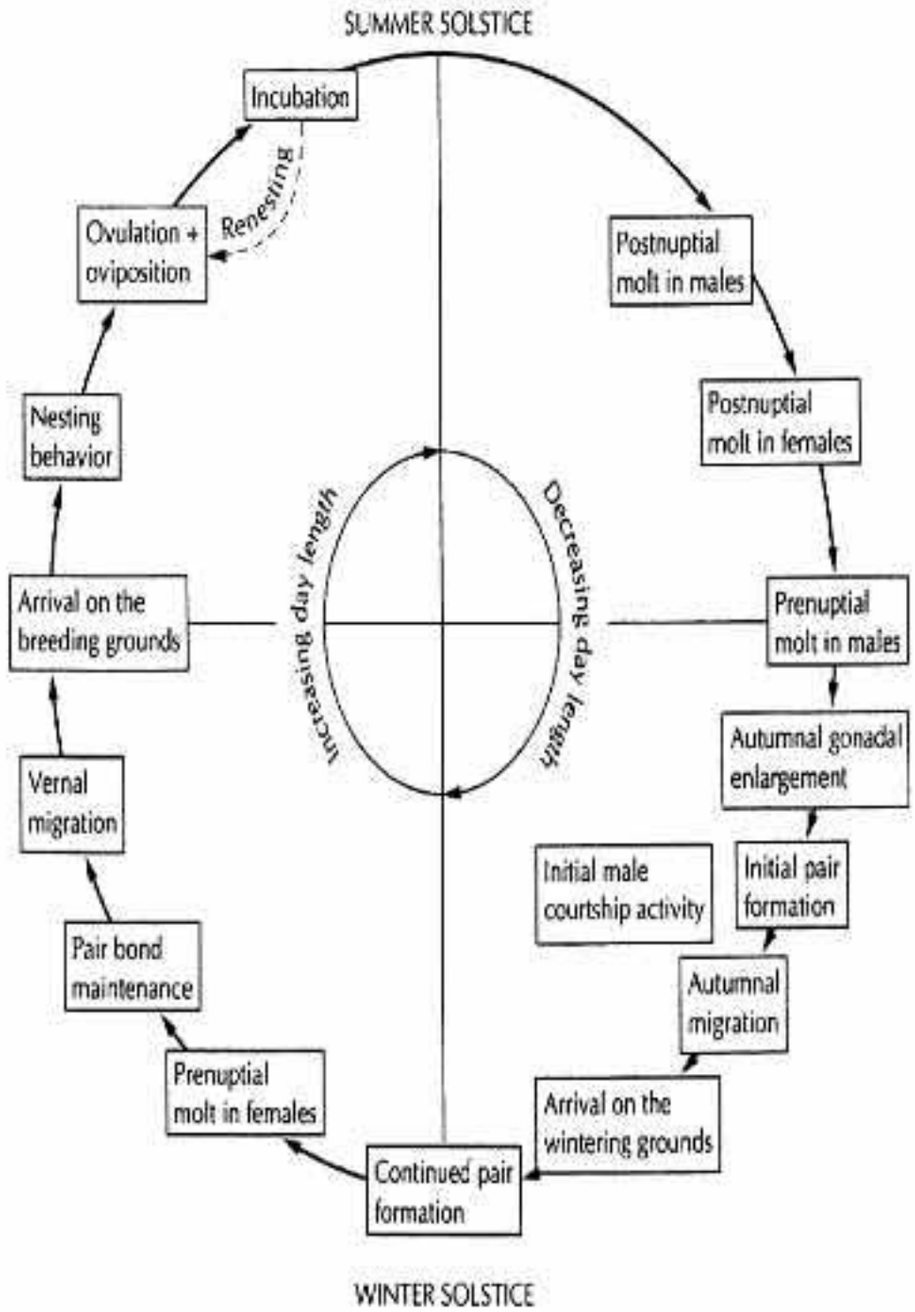


Human menstrual cycle

Atlantic fireworm fertilisation on the night before each quarter moon

Examples of innate rhythms

Some show circannual cycles (>1 year)



Examples of innate rhythms

Some show circannual cycles (>1 year)

- seasonal breeding, migration and hibernation

Examples of innate rhythms

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Bamboo plants flower every 7 years

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Bamboo plants flower every 7 years

Cicada reproductive peak two weeks every 13 or 17 years

Examples of innate rhythms

Some show circannual cycles (>1 year)

- seasonal breeding, migration and hibernation

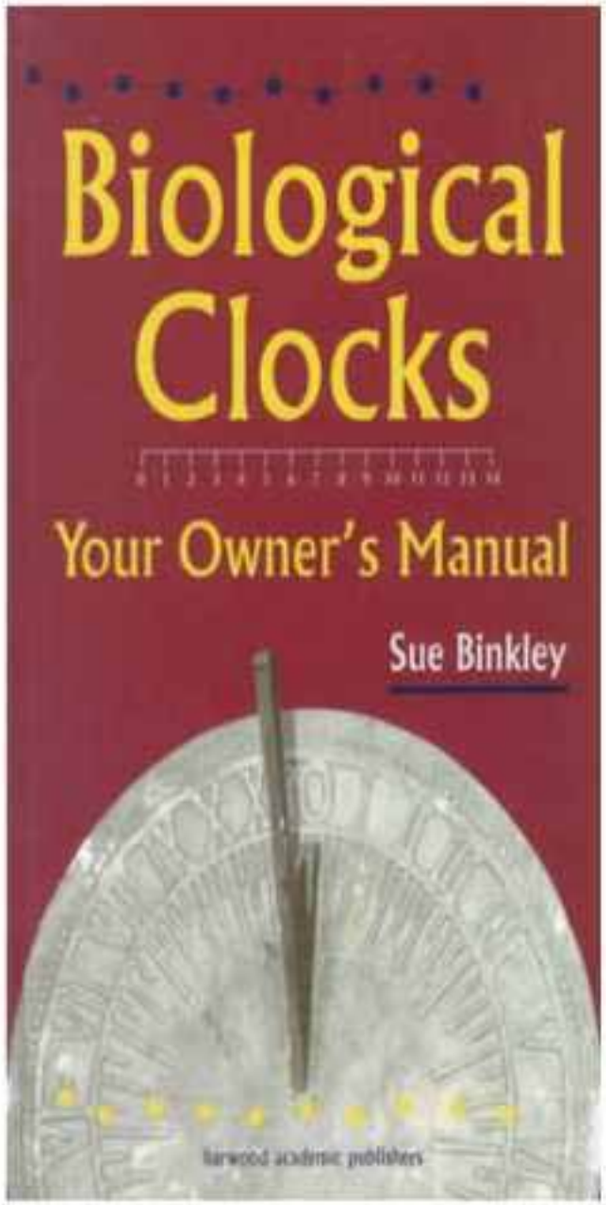
Bamboo plants flower every 7 years

Cicada reproductive peak two weeks every 13 or 17 years

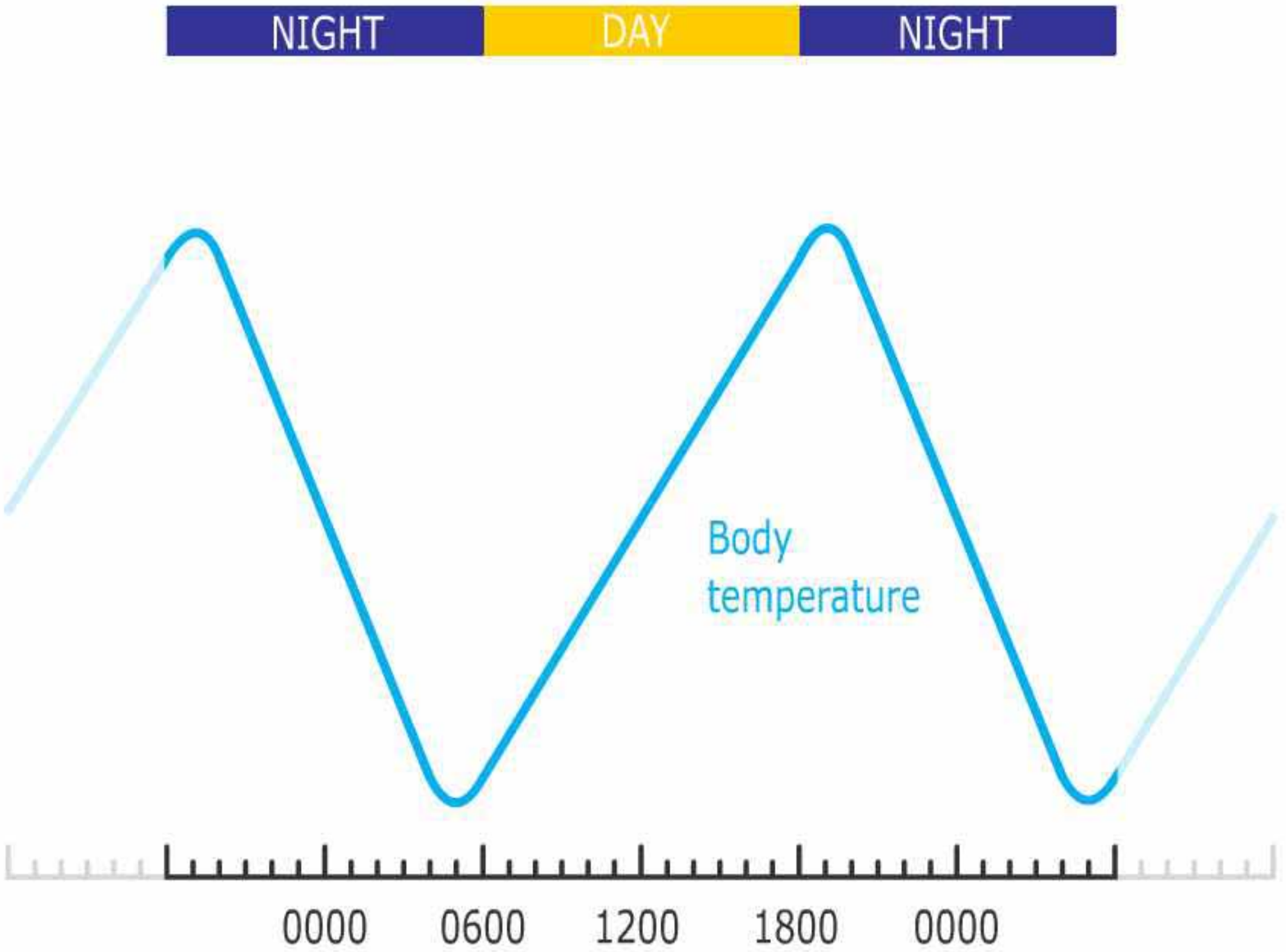
Agave Americana only flowers once every 100 years

Behavioural and physiological cycles

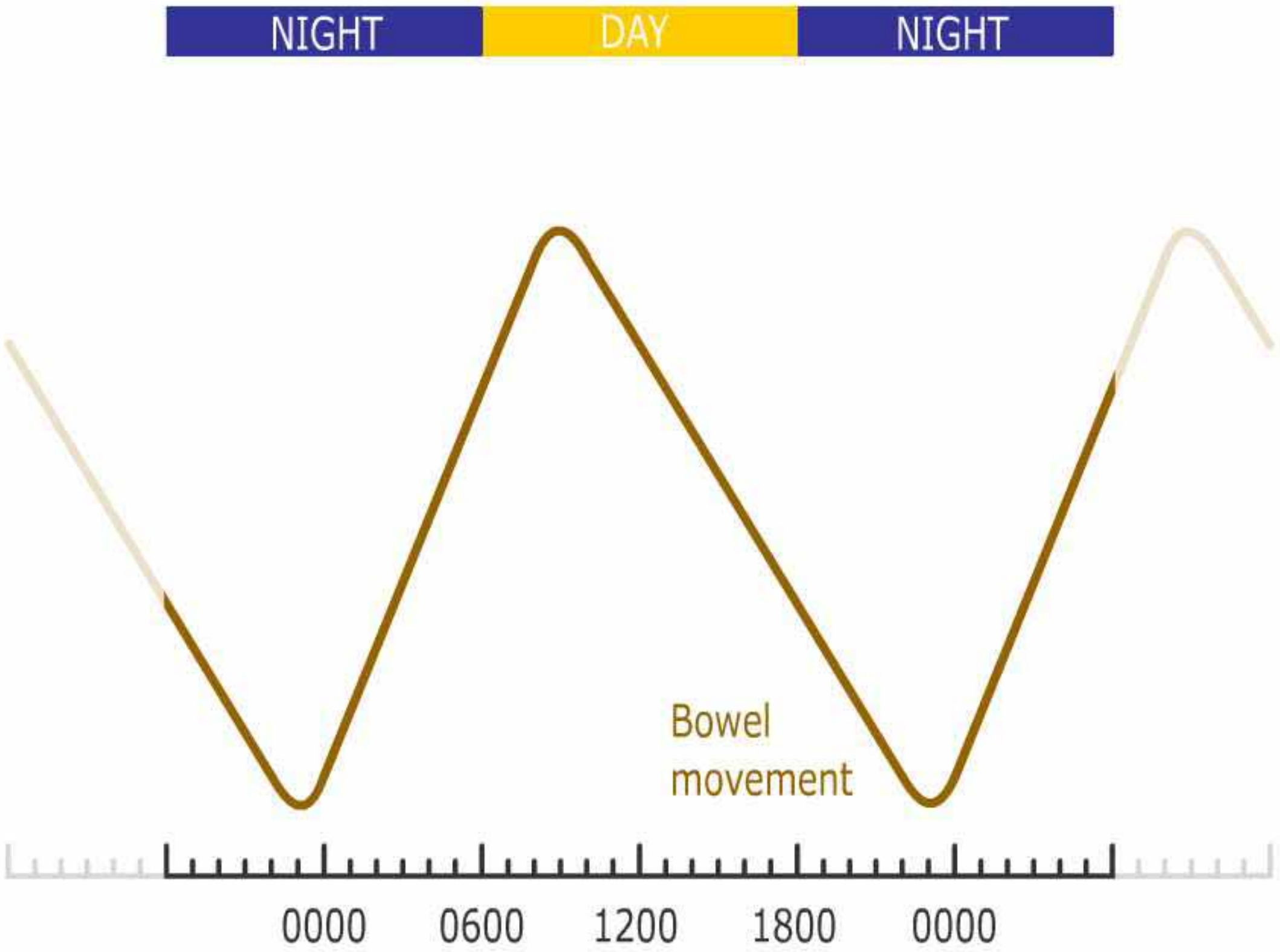
There is indeed a biological time for everything !



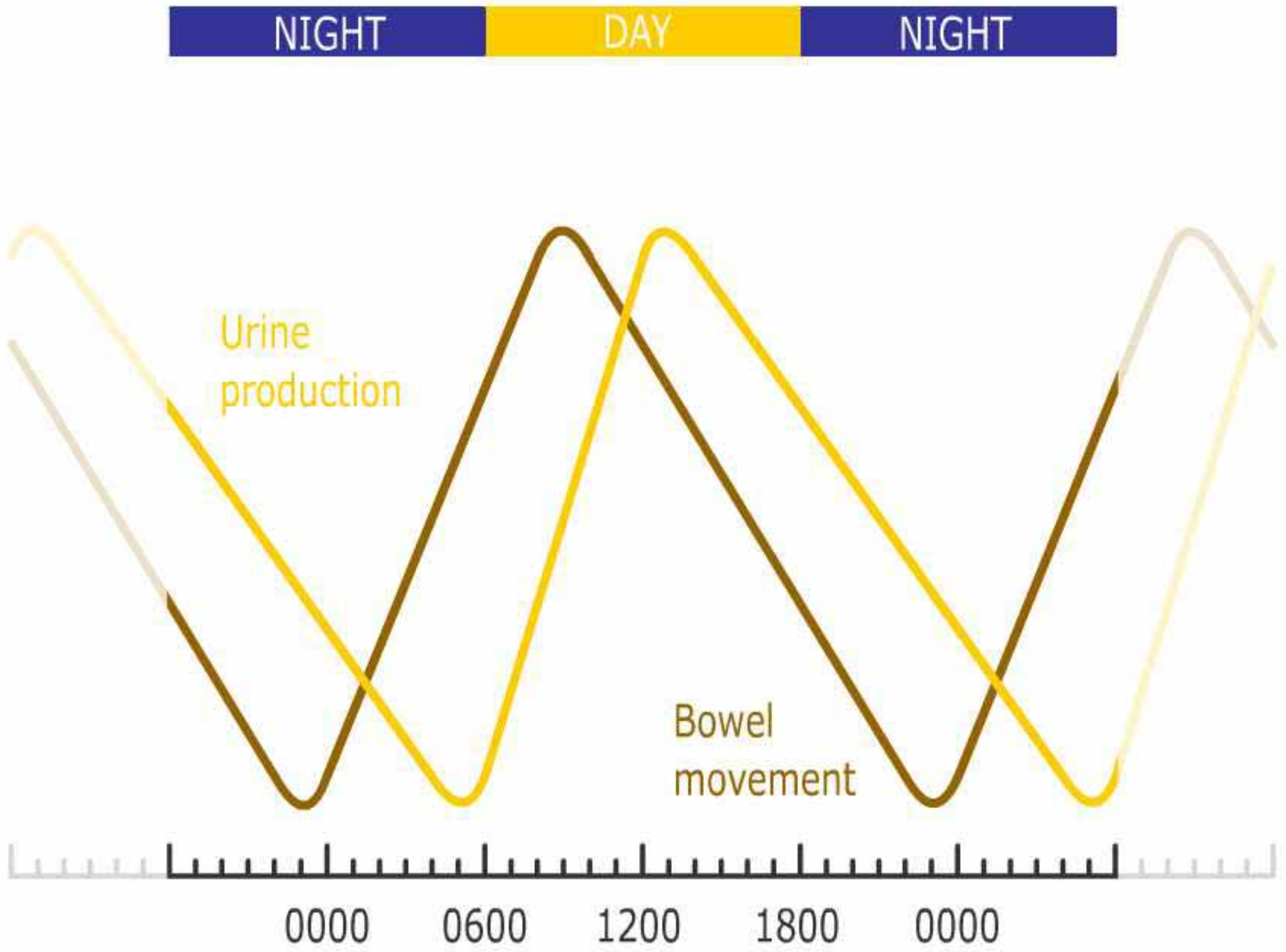
Behavioural and physiological cycles



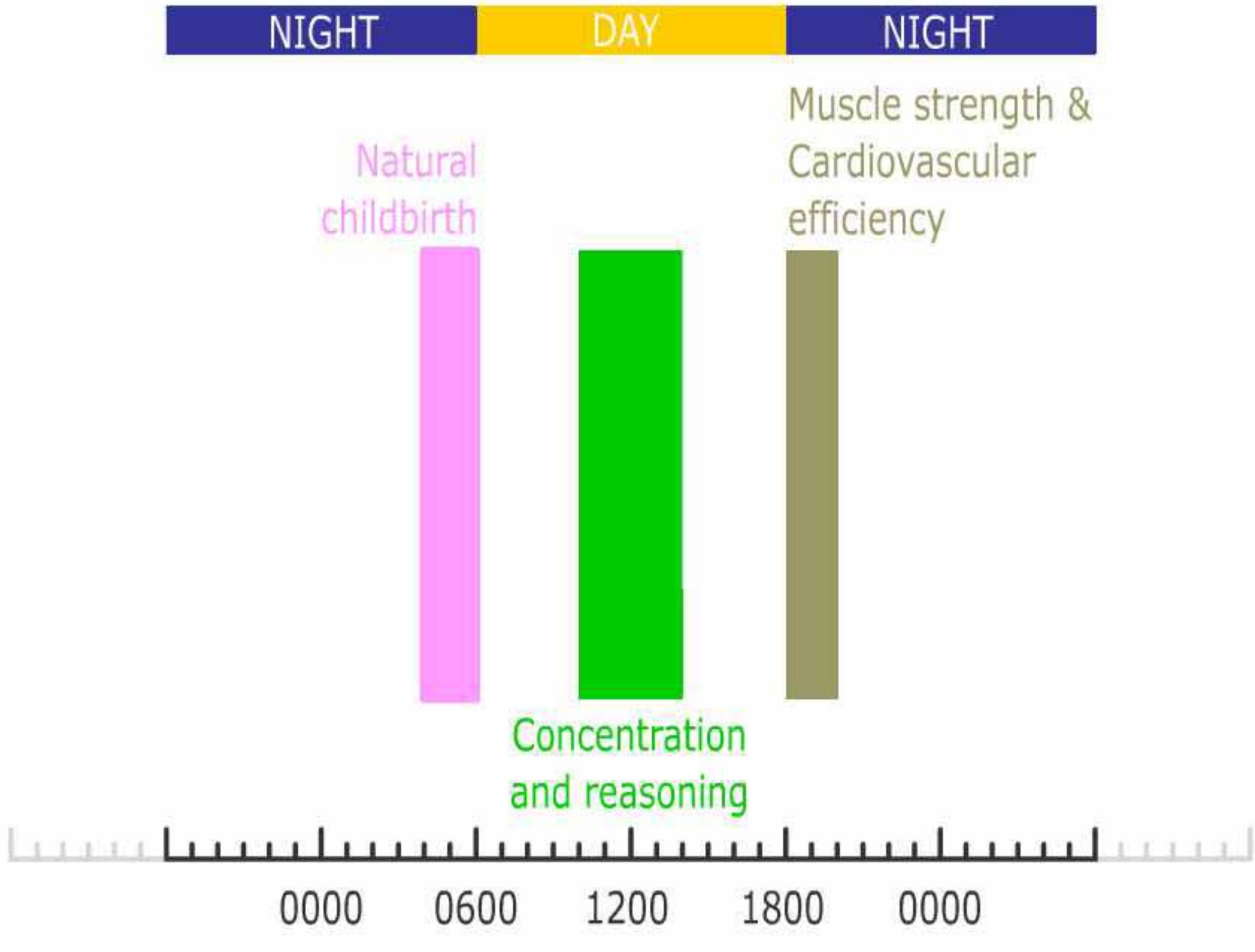
Behavioural and physiological cycles



Behavioural and physiological cycles



Behavioural and physiological cycles



Biochemical cycles

Uric acid concentration

Growth hormone

Prolactin

Cortisol

Glucose

Fight/Flight

Glycerol

Testosterone

Lymphocytes

NK-cell activity

Eosinophils

Blood viscosity

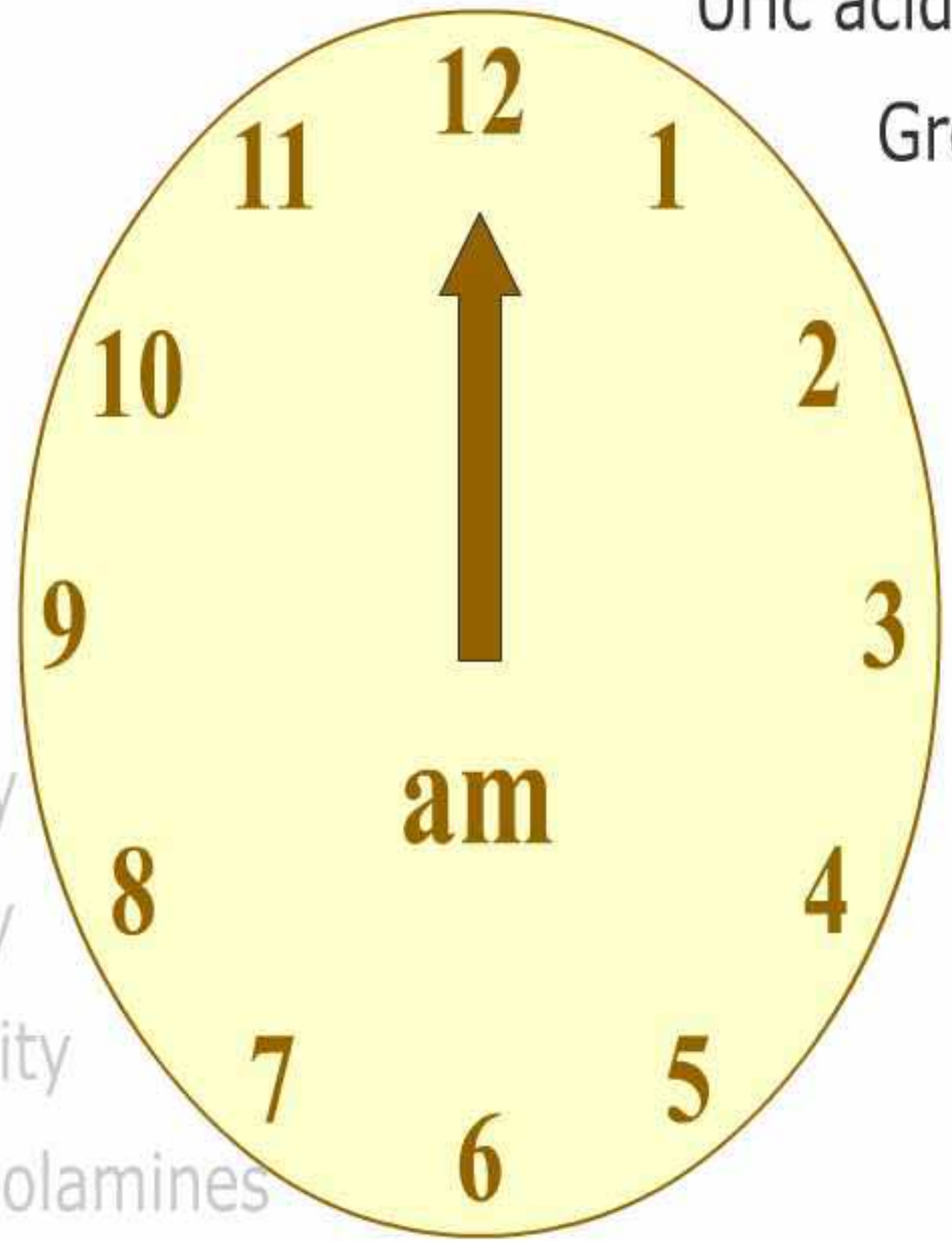
Melatonin

Platelet viscosity

LH, TSH

Plasma catecholamines

ACTH, FSH



Susceptibility to disease

Myocardial infarction

Death

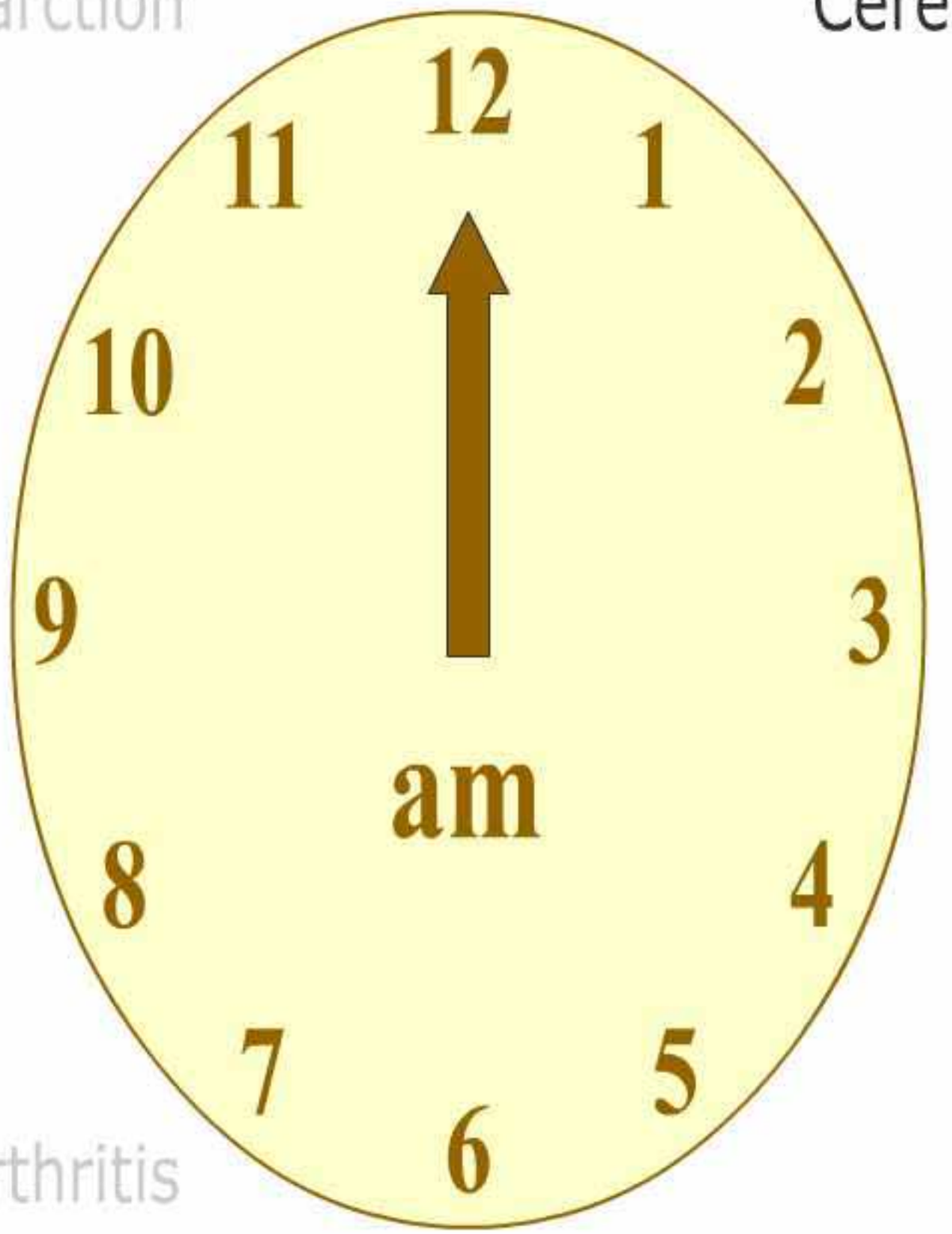
Stroke

Angina

Migraine

Hay fever

Rheumatoid arthritis



Cerebral infarction

Gout

Gall bladder symptoms

Gastric ulcer

Asthma

SIDS

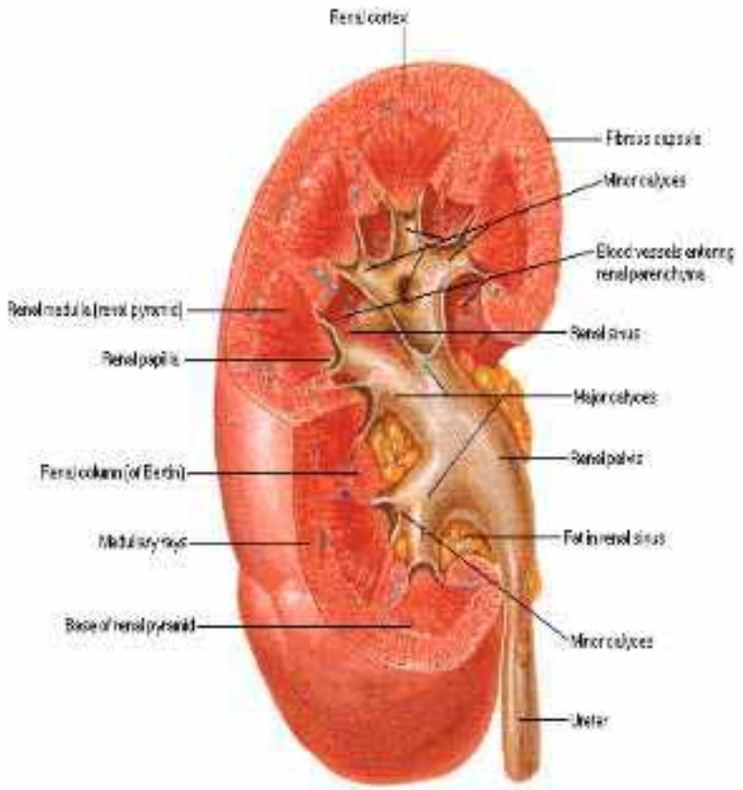
Why ?

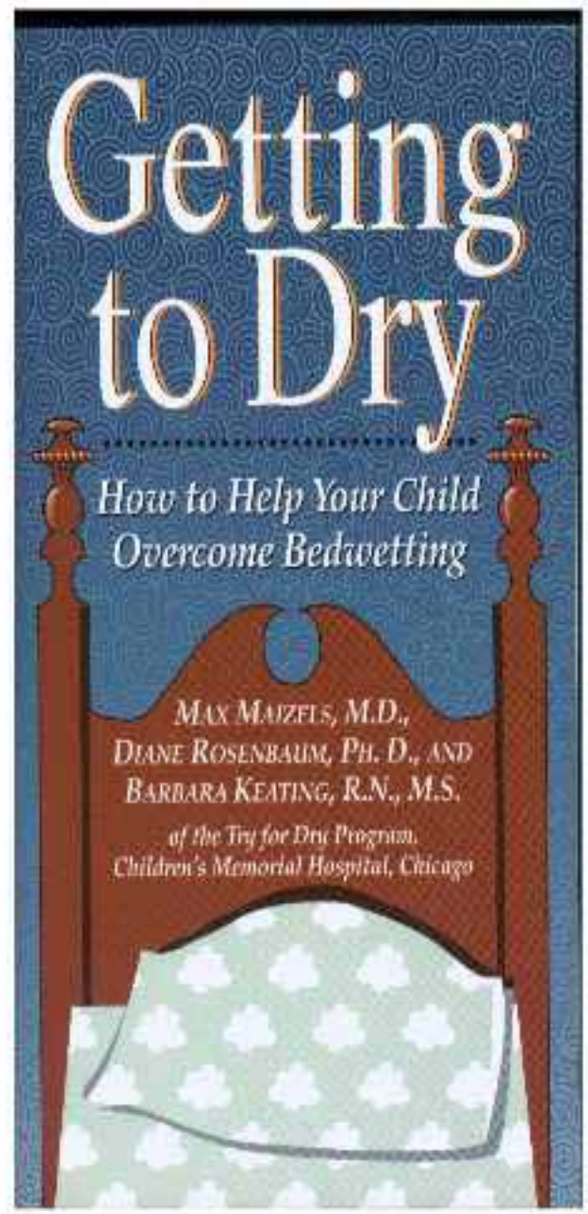
Time is God's way of keeping everything from happening at once

Why ?

Time is God's way of keeping everything from happening at once

Your kidneys take a rest at night so
you don't have to wake up for a pee !





Why ?

There's no point producing kids when it's -30°C outside and there's no food

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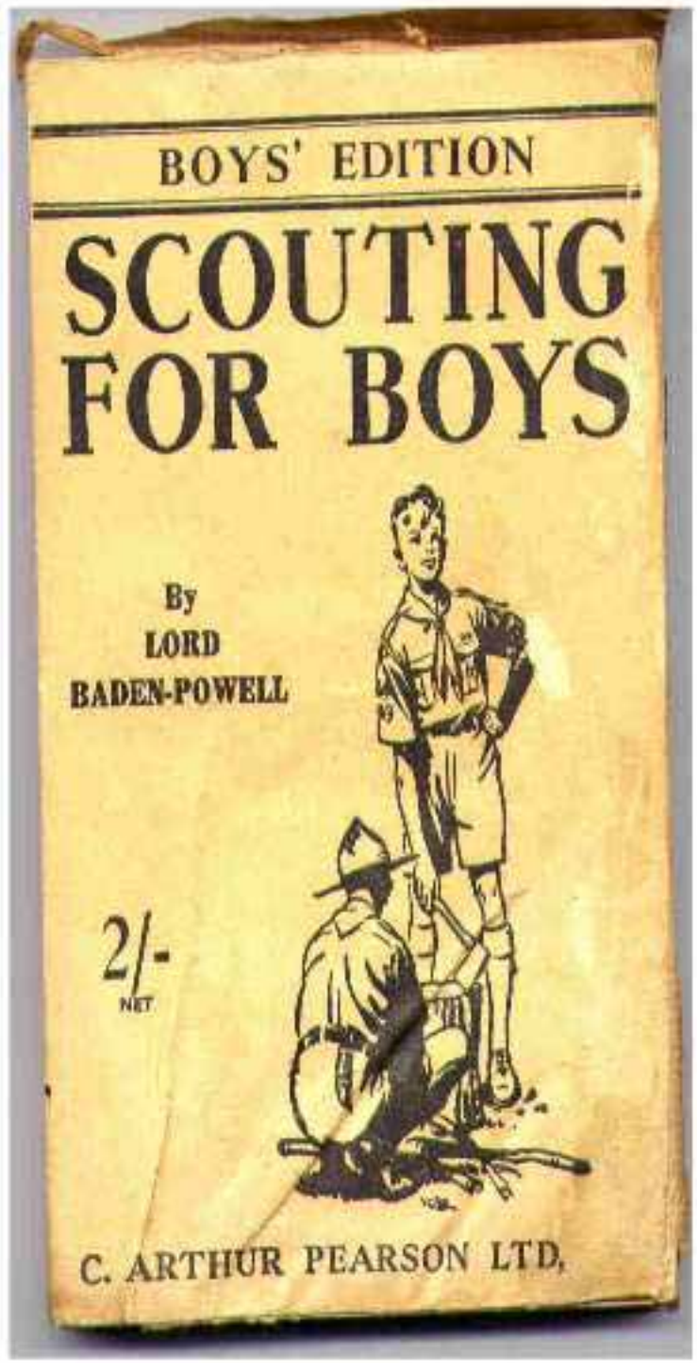
Migrating or hibernating at the wrong time would be a problem

Why ?

There's no point producing kids when it's -30°C outside and there's no food

Migrating or hibernating at the wrong time would be a problem

Being prepared



Why ?

There's no point producing kids when it's -30°C outside and there's no food

Migrating or hibernating at the wrong time would be a problem

Being prepared

Getting out of the noon day sun

Waking up ready for action

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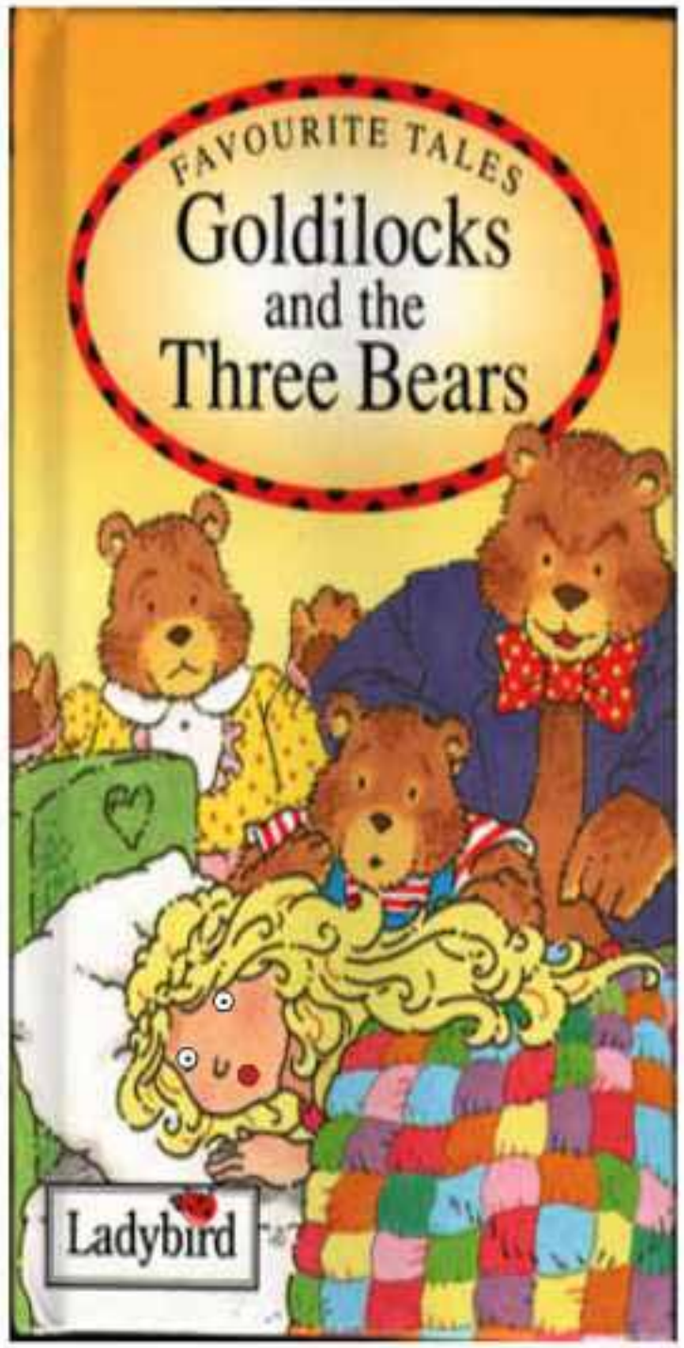
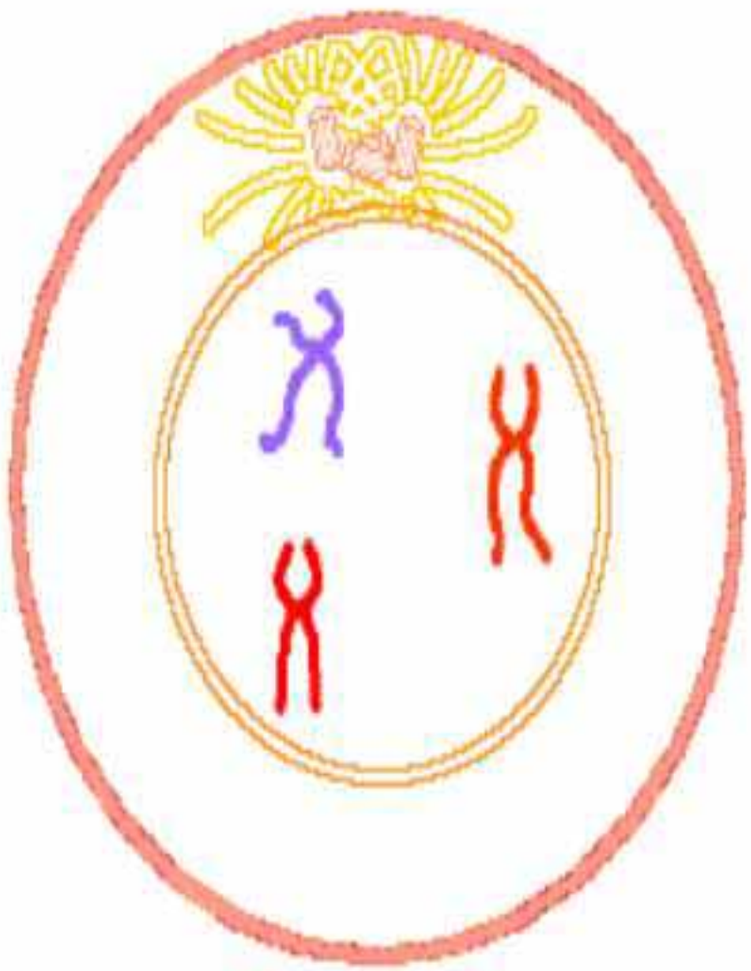


Why ?

A biological clock allows us to anticipate nature as well as exist in harmony with it

Where ?

Cellular clocks: all cells can show cyclic activity

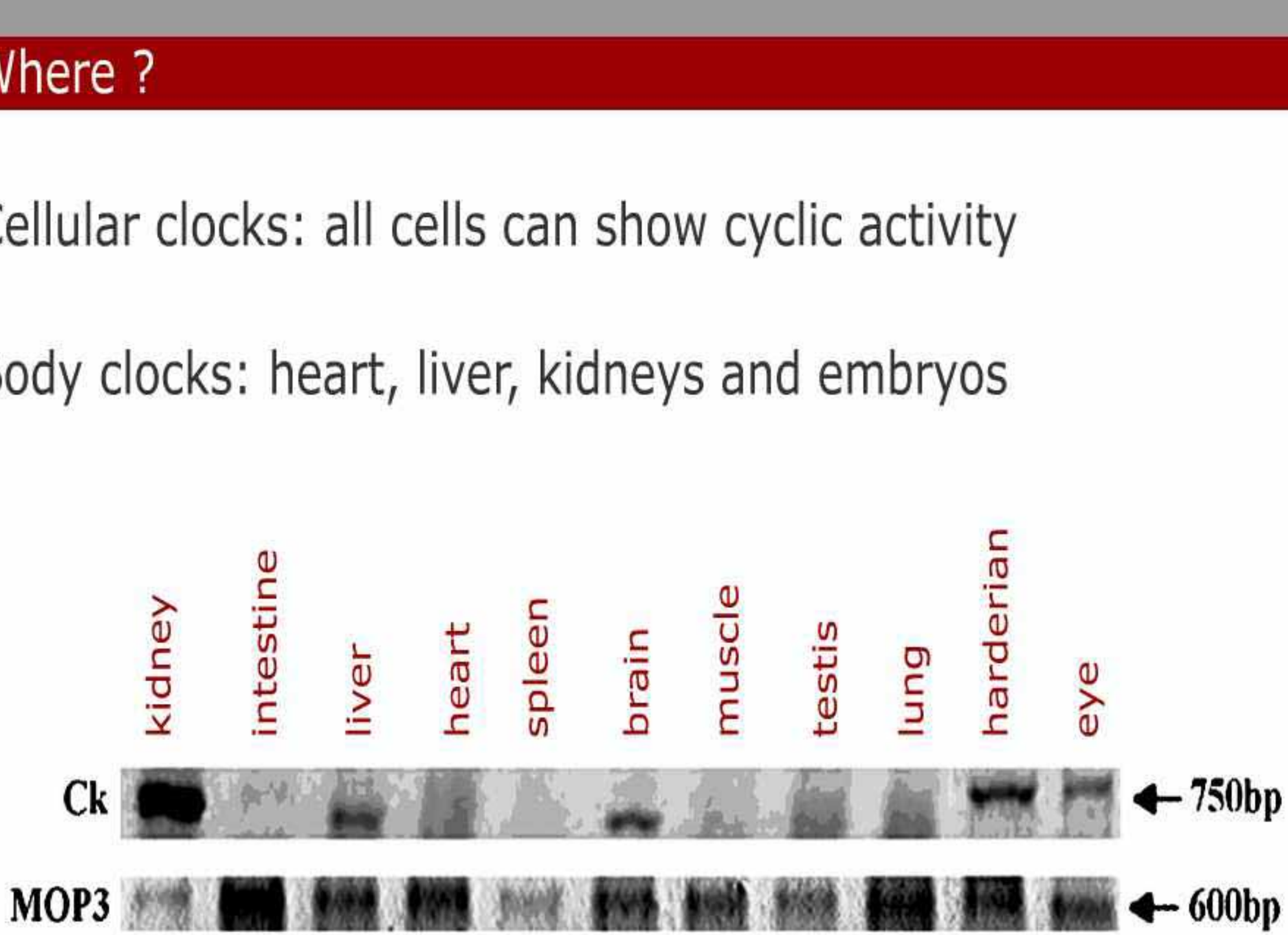


Prophase:
- condensation of chromosomes
- disappearance of nucleoli and nuclear erwelope

Where ?

Cellular clocks: all cells can show cyclic activity

Body clocks: heart, liver, kidneys and embryos

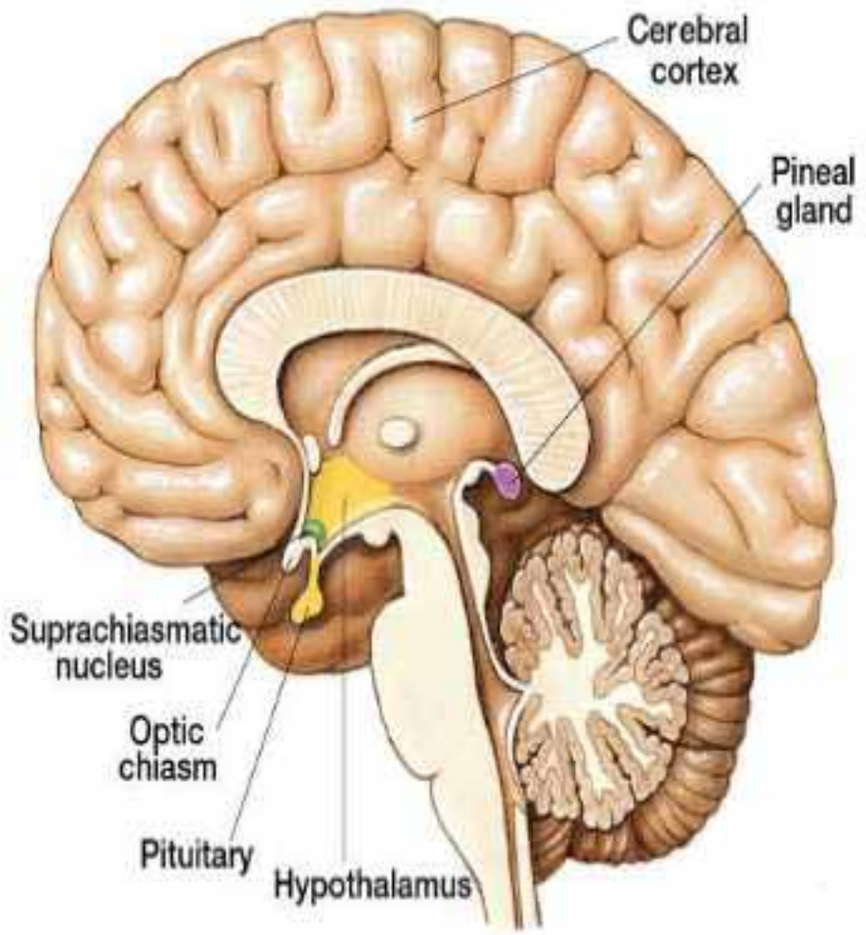


Tissue distribution of Clock and MOP3 in the mole rat. Avivi *et al* PNAS 2001

Where ?

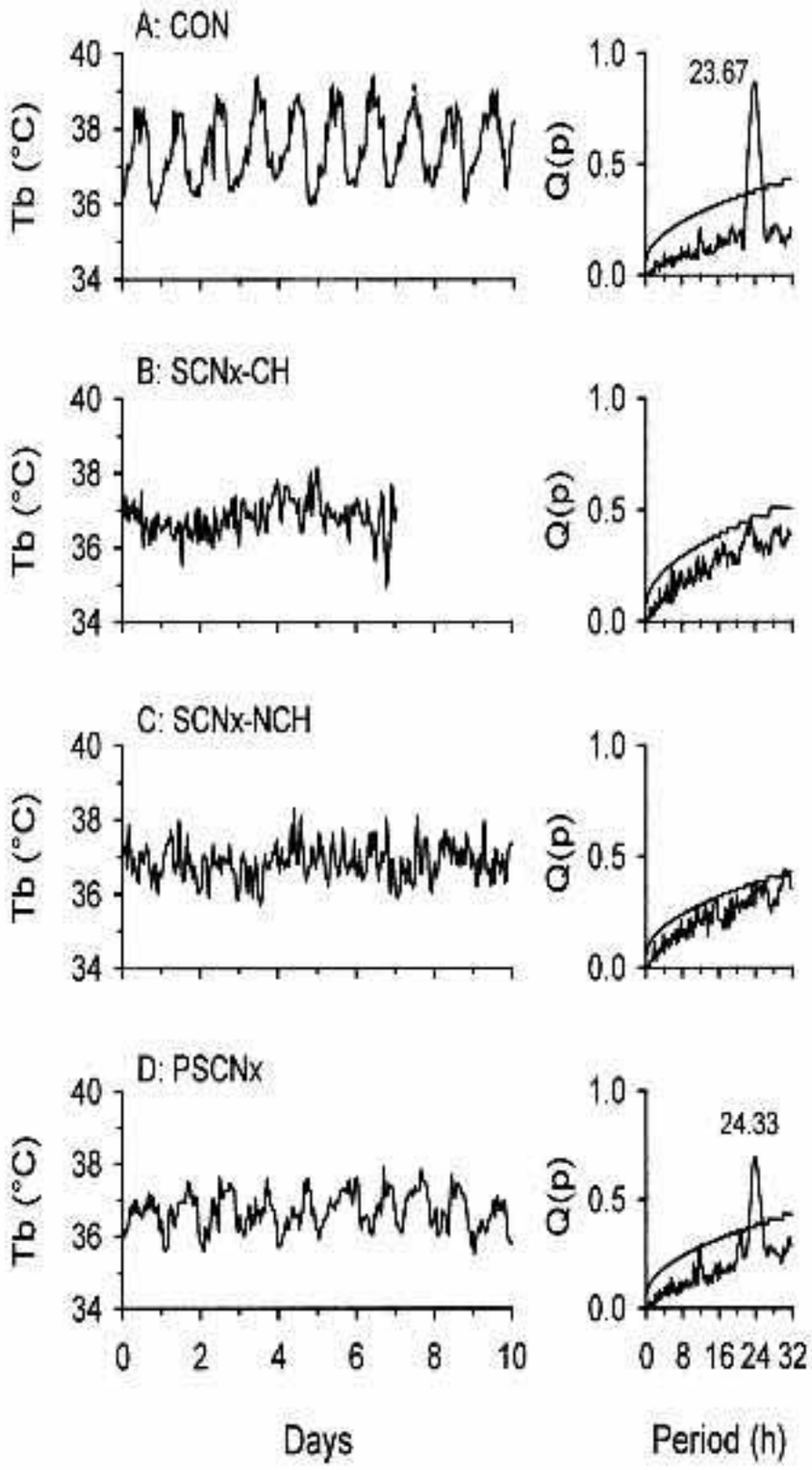
Brain clocks: the suprachiasmatic nucleus (SCN)

20,000 neurones under the neocortex



Where ?

With no SCN normally rhythmic cycles become arrhythmic

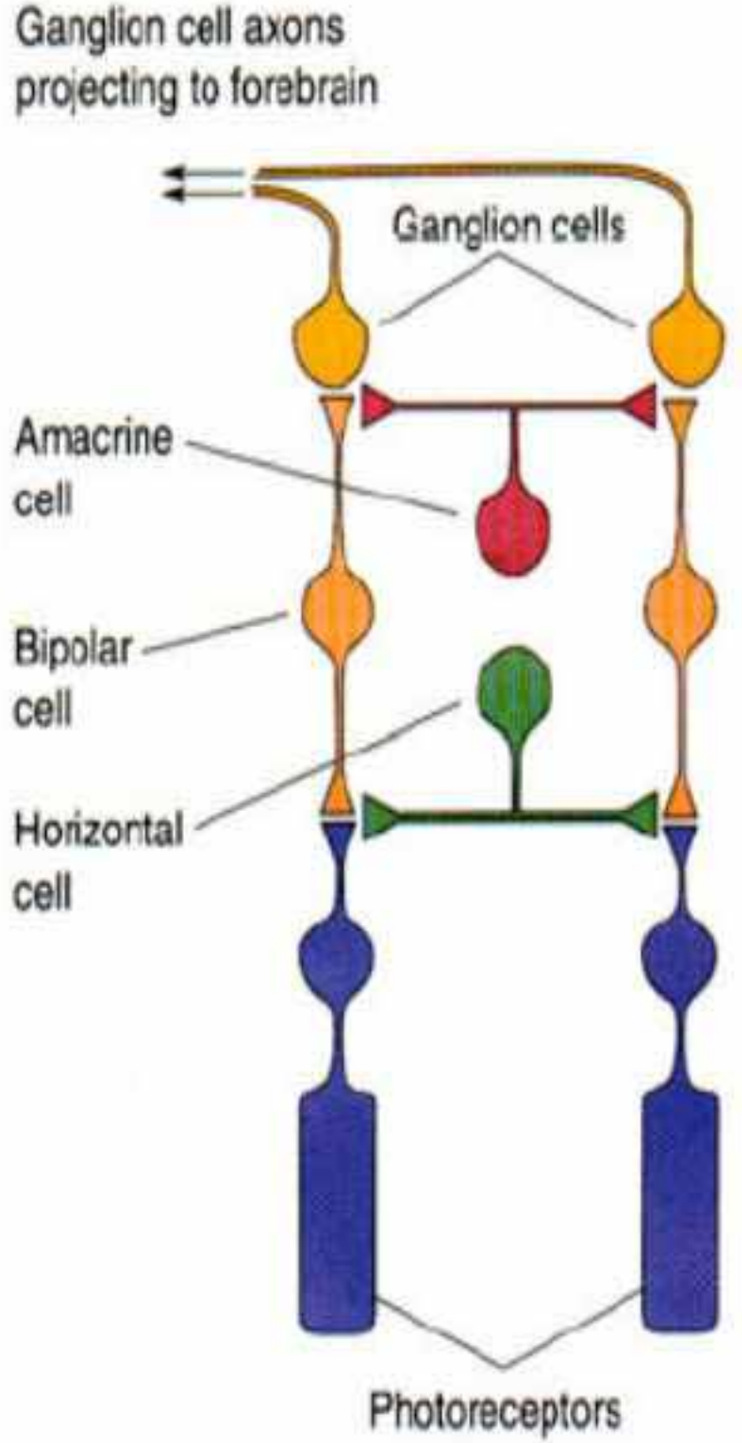


Ruby *et al* J. Neuroscience (2002)

Where ?

With no SCN normally rhythmic cycles become arrhythmic

SCN receives direct projections from special photoreceptors

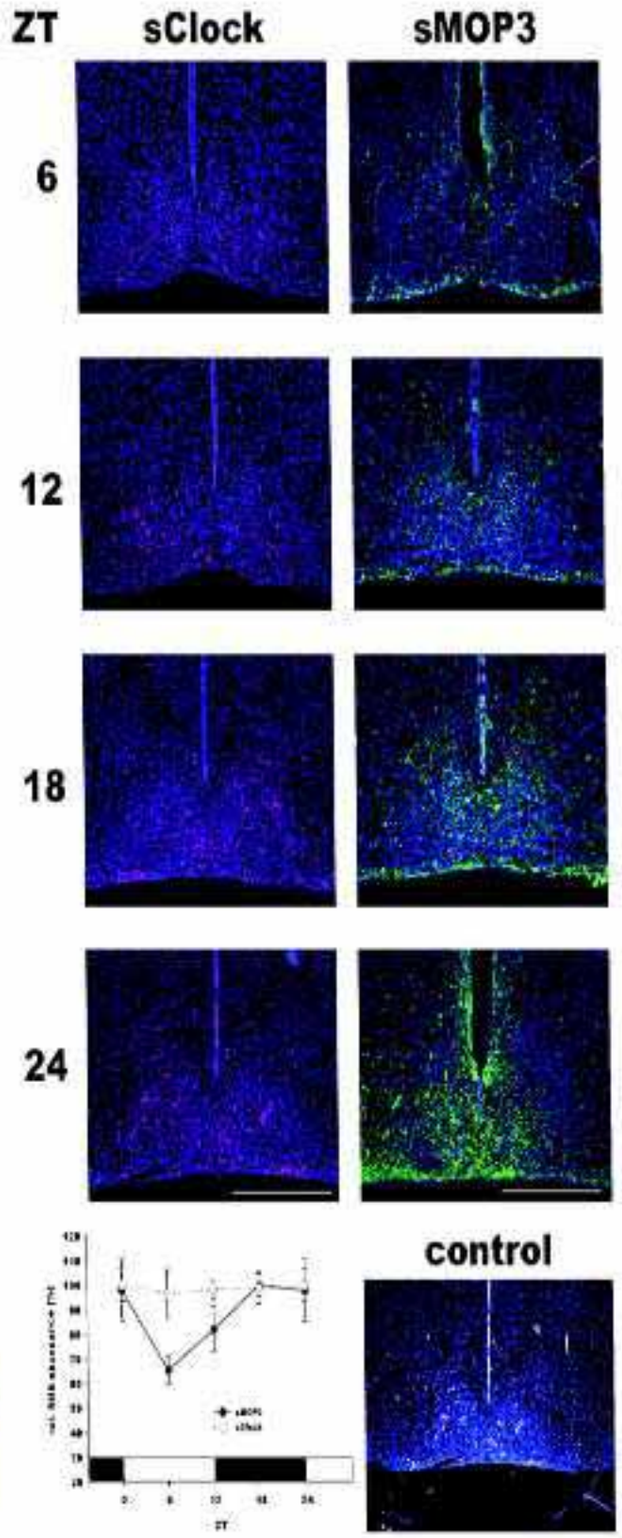


Where ?

With no SCN normally rhythmic cycles become arrhythmic

SCN receives direct projections from special photoreceptors

The blind can still sometimes show photoperiodic responses



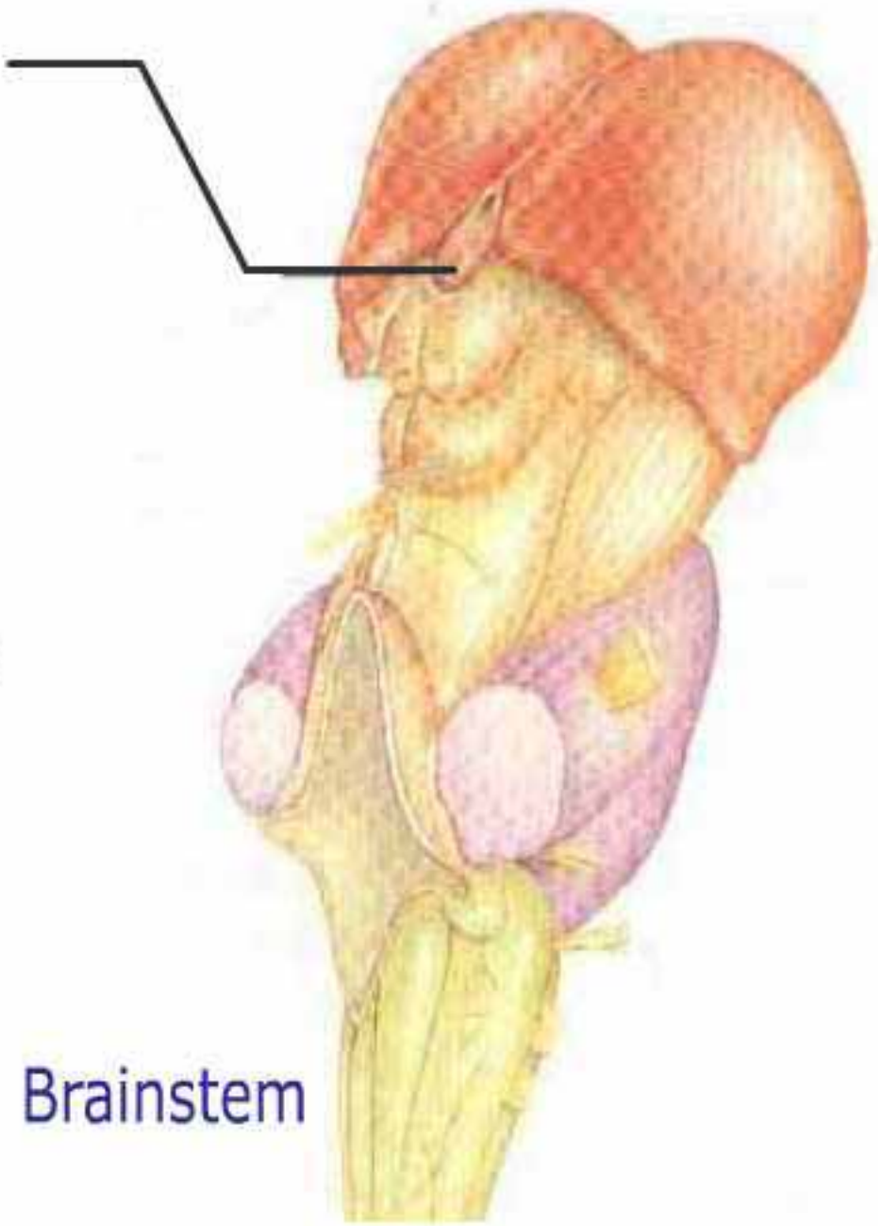
Oscillation of MOP3 in the blind mole rat
Avivi *et al* PNAS 2001

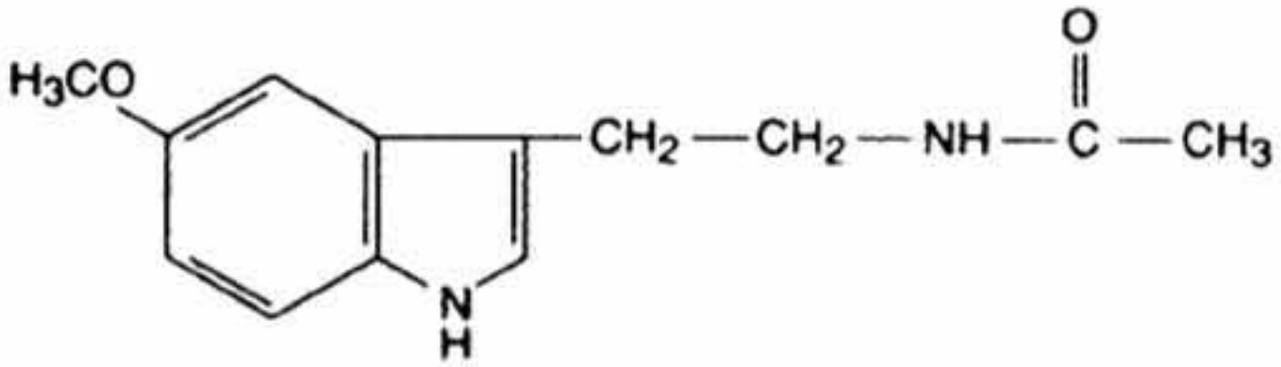
Where ?

How does the SCN clock communicate time to the brain ?

Direct connections to the pineal gland

Regulates release of melatonin





Where ?

How does the SCN clock communicate time to the brain ?

Direct connections to the pineal gland

Regulates release of melatonin

Pineal gland is not the seat of the soul

Descartes

Where ?

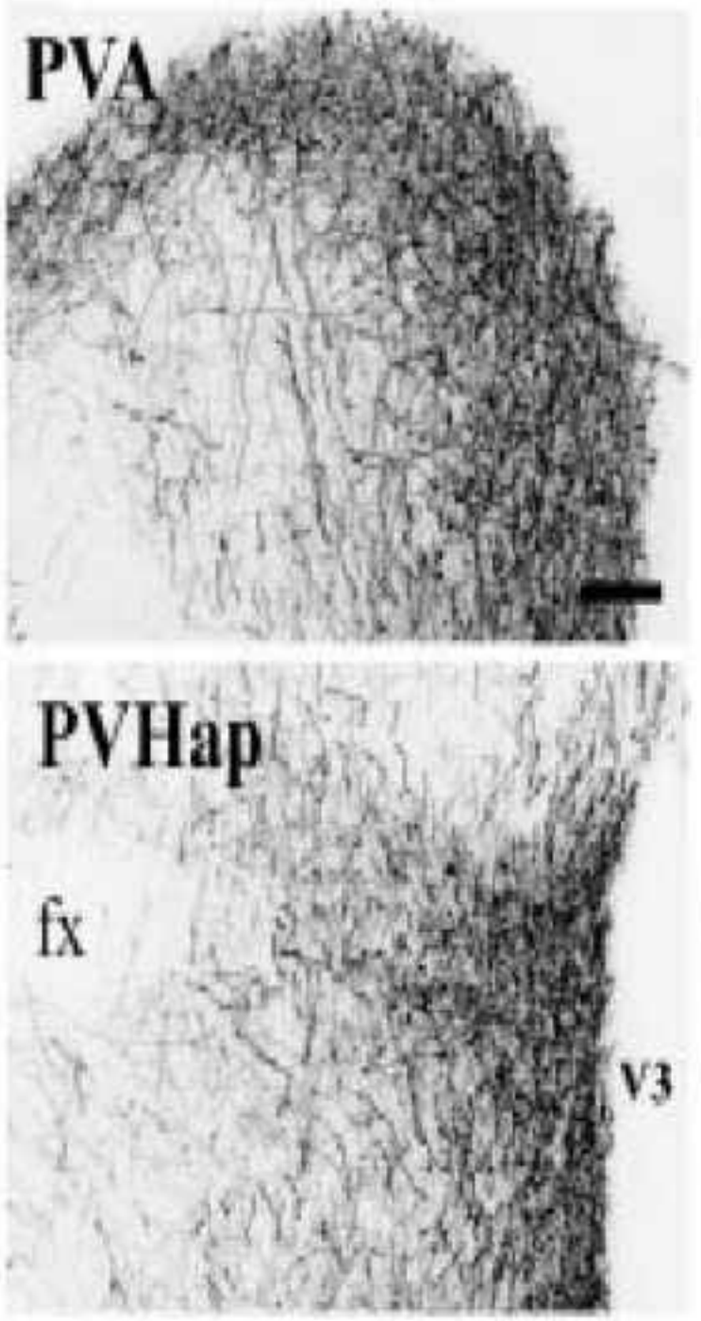
How does the SCN clock communicate time to the brain ?

Direct connections to the pineal gland

Regulates release of melatonin

Pineal gland is not the seat of the soul

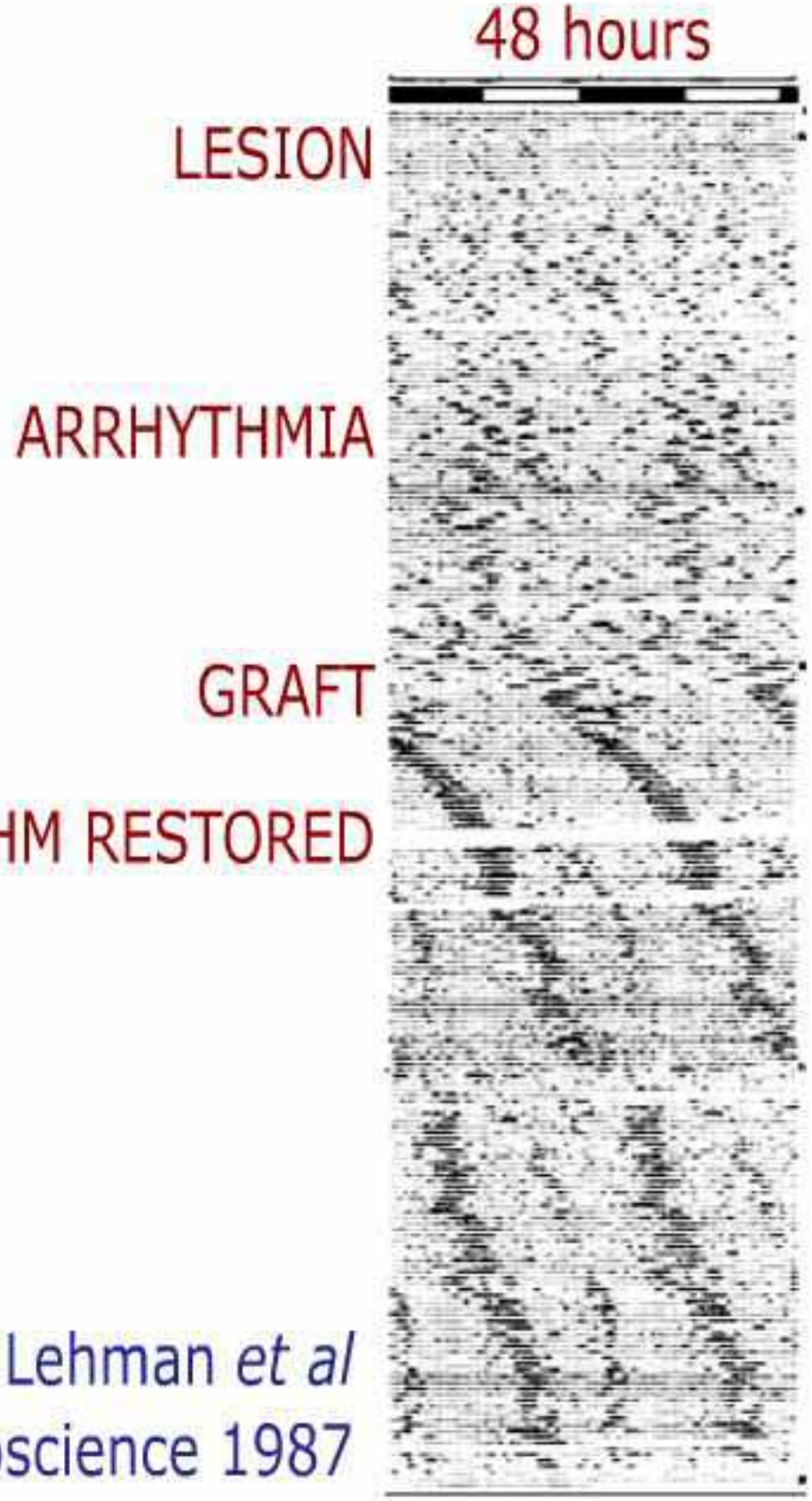
SCN connections with the rest of the brain are sparse



Kriegsfeld *et al* J. Comp. Neurology (2004)

Where ?

Fetal SCN grafts restore rhythmic function in animals with no SCN



Lehman *et al*
J. Neuroscience 1987

Where ?

Fetal SCN grafts restore rhythmic function in animals with no SCN

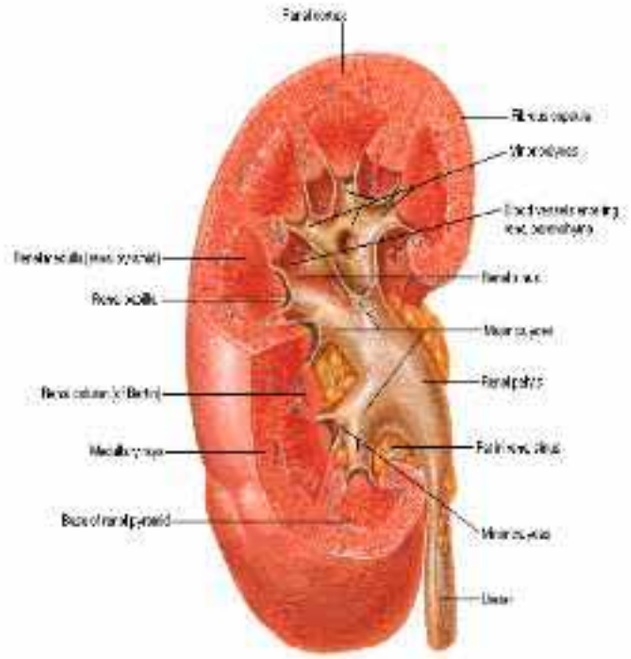
The Syrian Hamster tau mutation
- a 22 vs 24.1h clock

SCN must be able to communicate time chemically

Where ?

The only chemical messengers identified so far are:

Arginine vasopressin

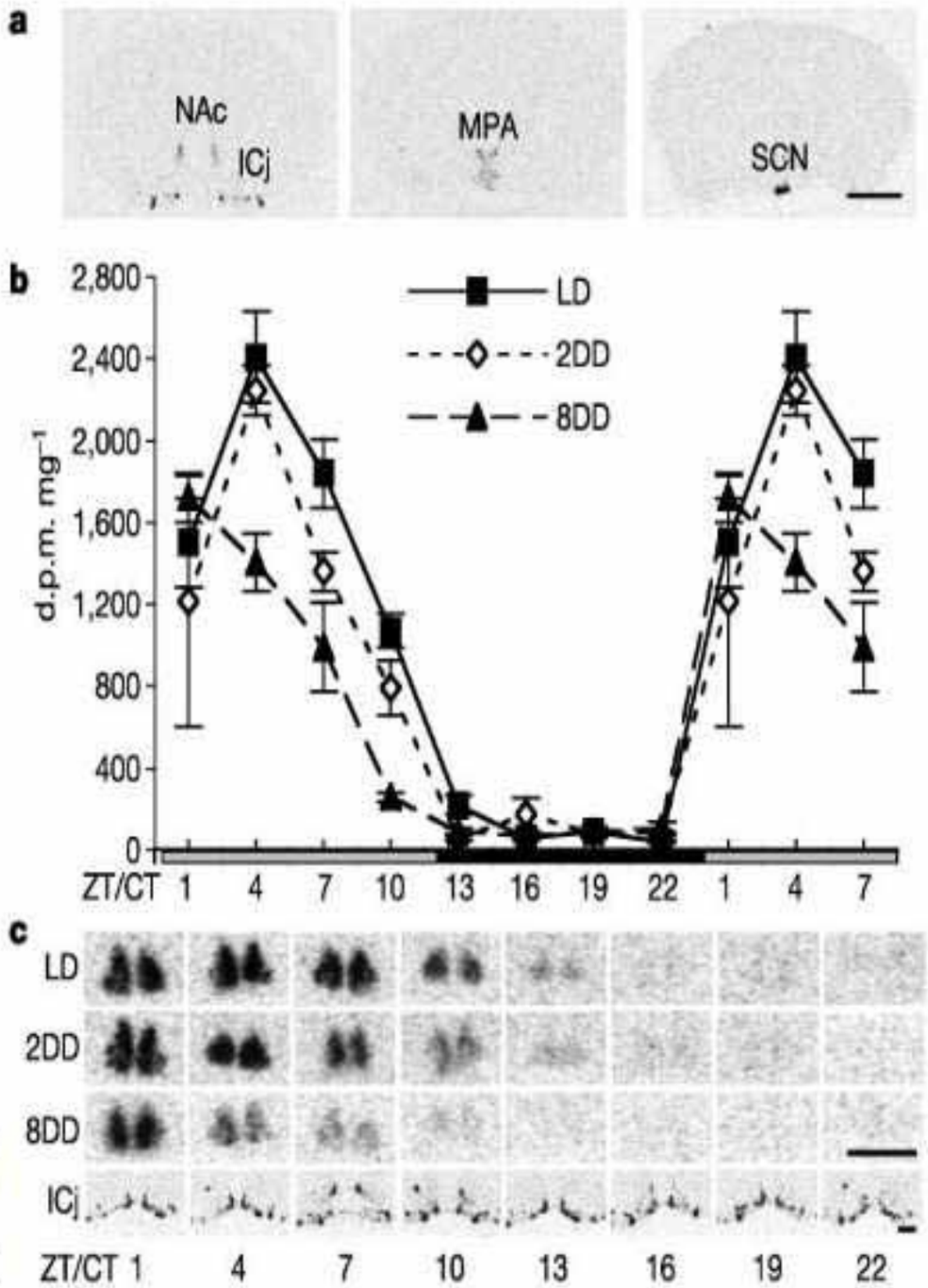


Where ?

The only chemical messengers identified so far are:

Arginine vasopressin

Prokineticin



Cheng *et al*
Nature 2002

Where ?

The brain clock and seasonal rhythms

Seasonal reproductive, migratory and hibernation behaviours

Where ?

The brain clock and seasonal rhythms

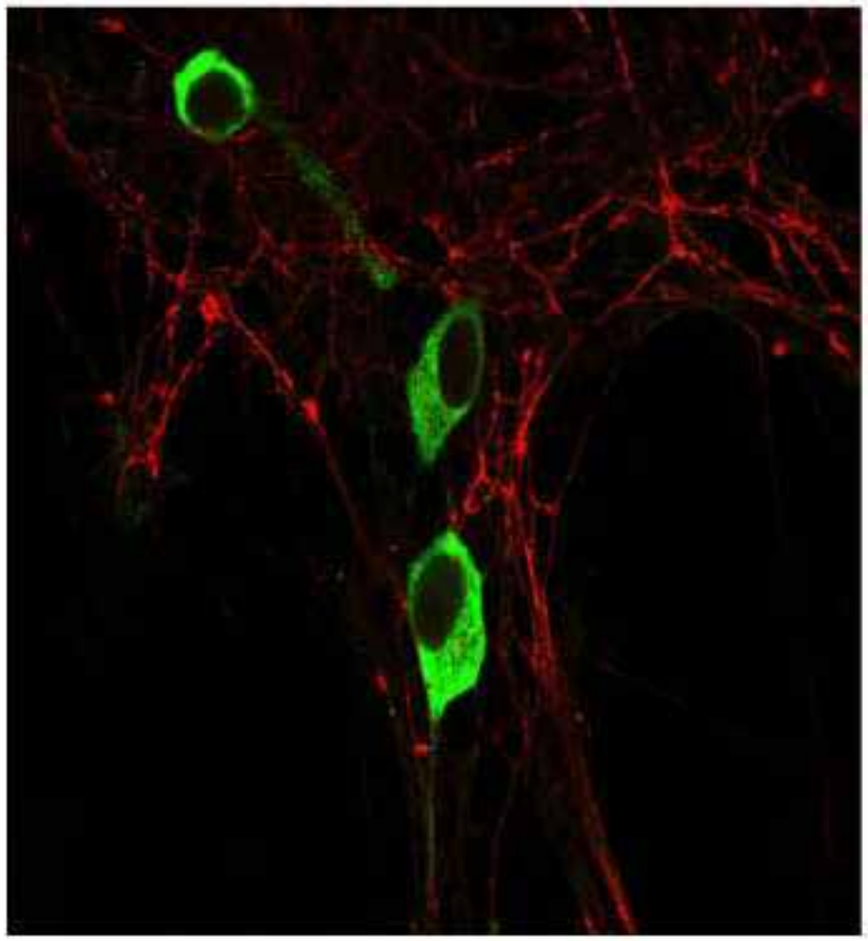
Seasonal reproductive, migratory and hibernation behaviours

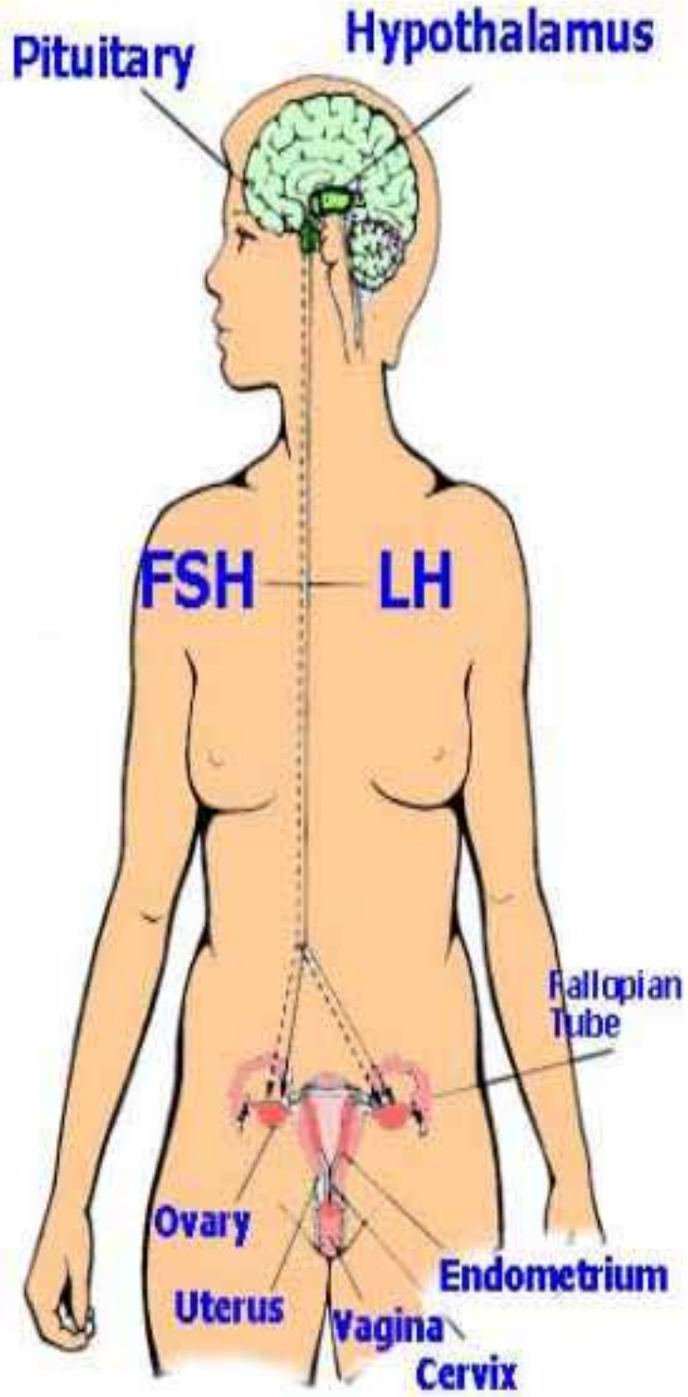
Without the SCN these become arrhythmic

Where ?

SCN reads duration of pineal melatonin

Drives brain control of ovulation



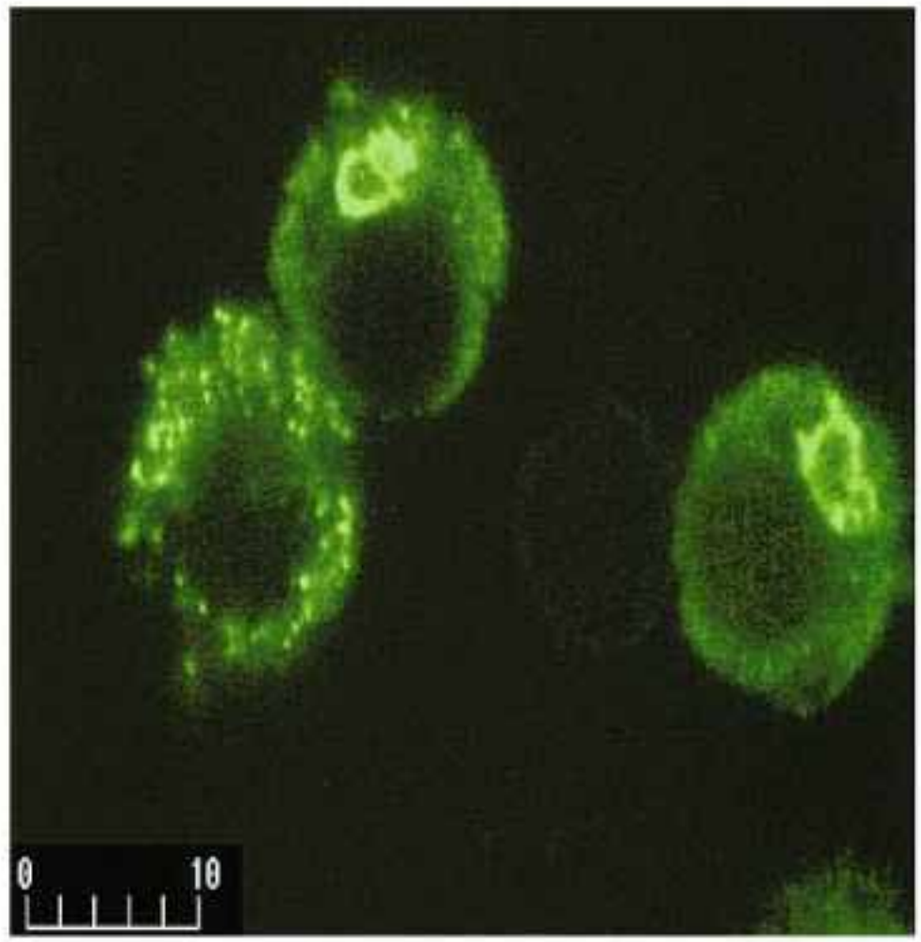


Where ?

SCN reads duration of pineal melatonin

Drives brain control of ovulation

Also controls prolactin release



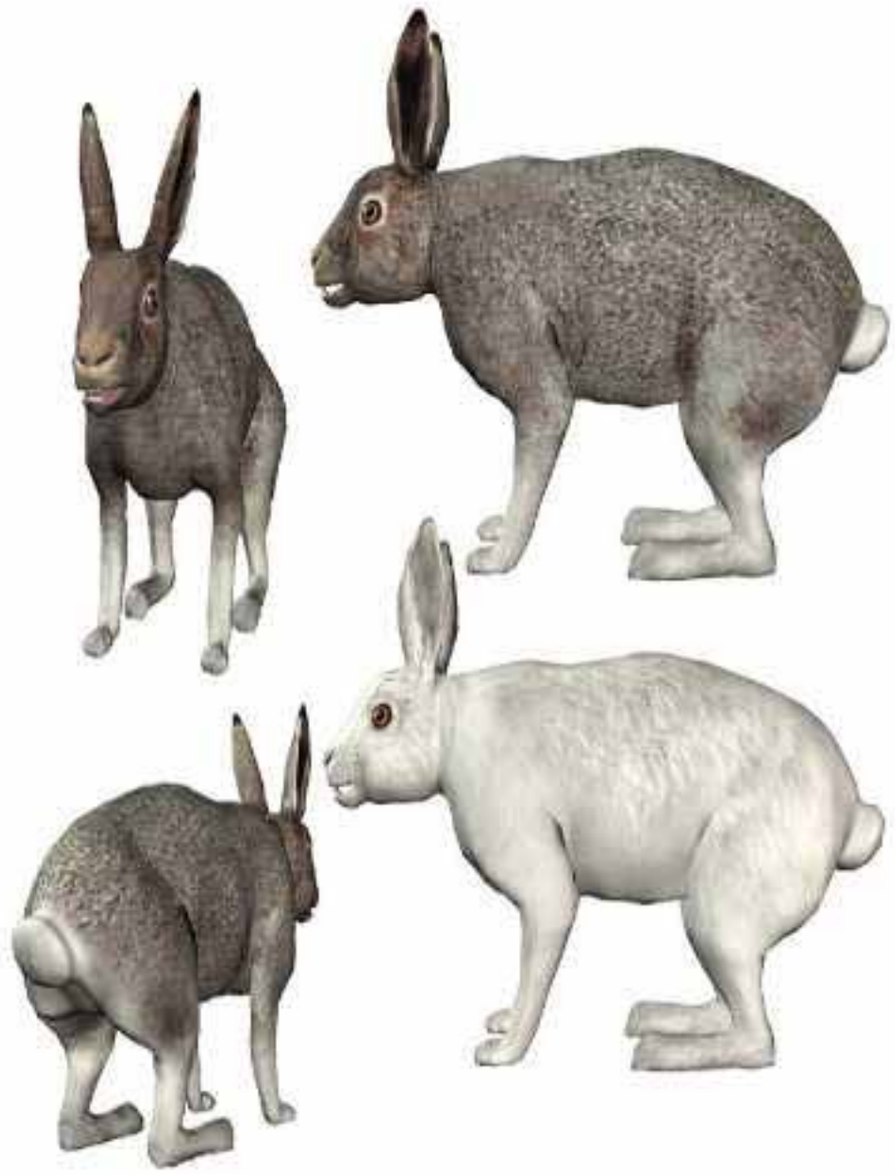
Where ?

SCN reads duration of pineal melatonin

Drives brain control of ovulation

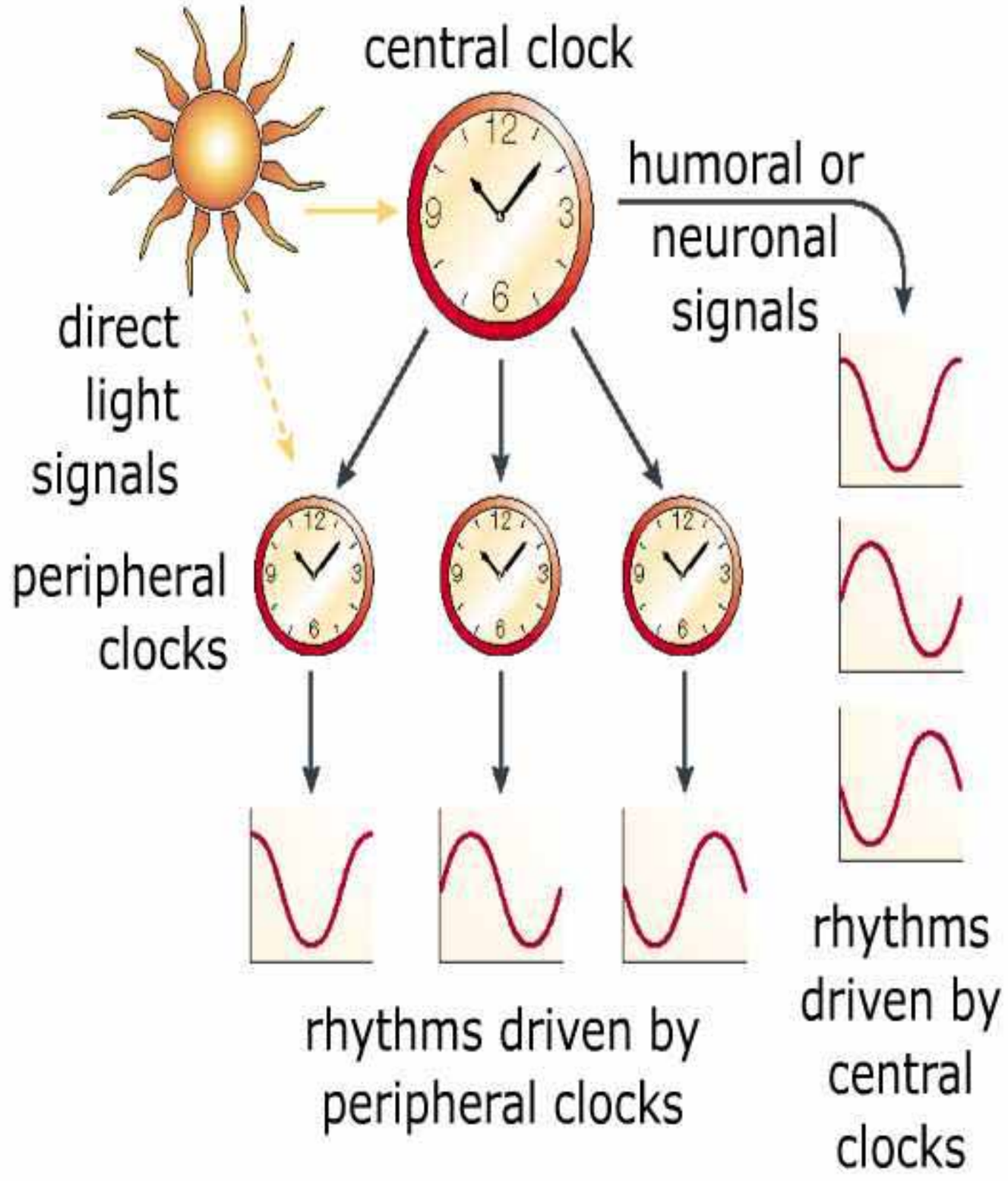
Also controls prolactin release

Affects food intake, metabolic rate, winter coat length and colour



Where ?

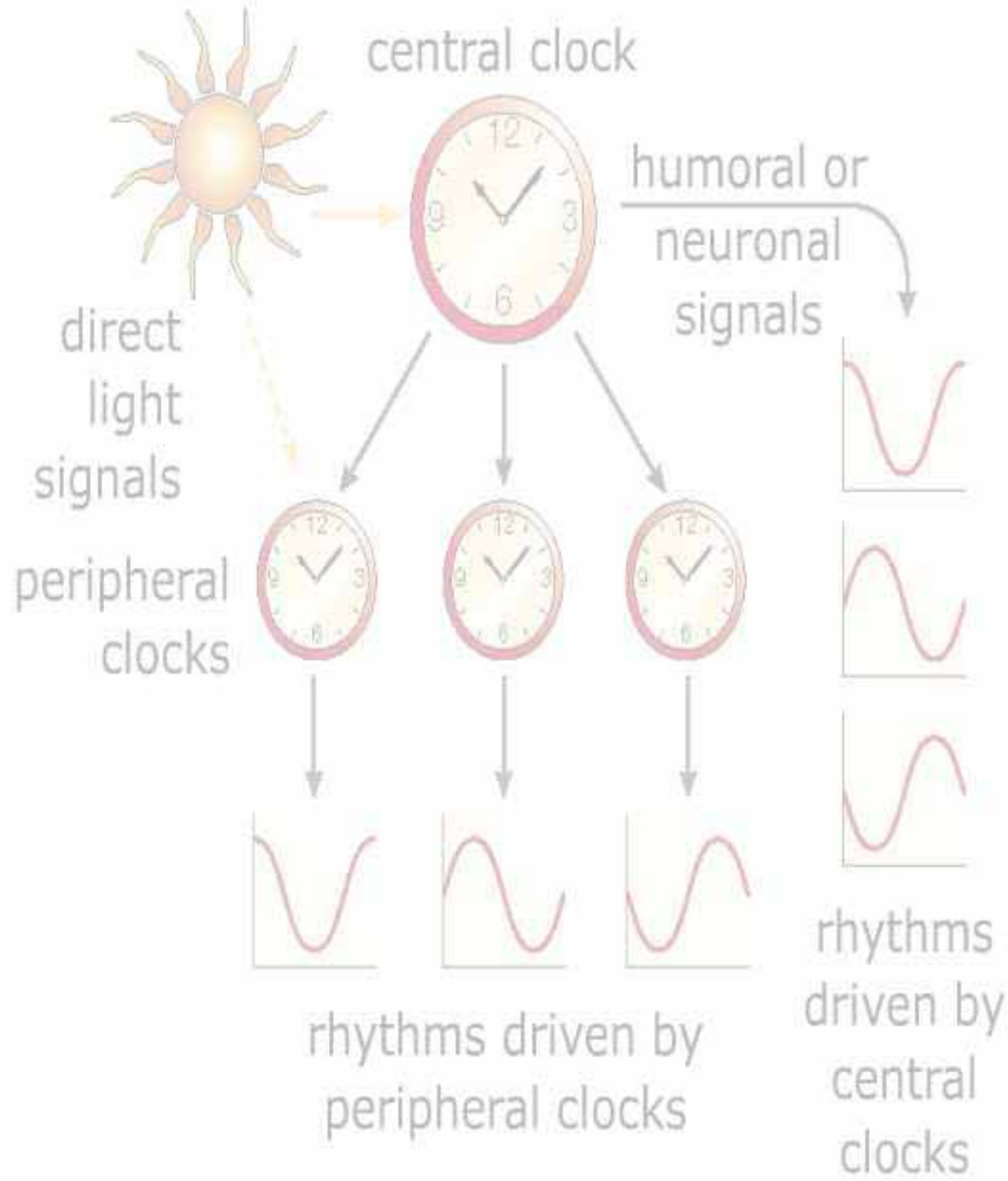
Is the SCN the body's master clock ?



Where ?

Is the SCN the body's master clock ?

Not completely



Where ?

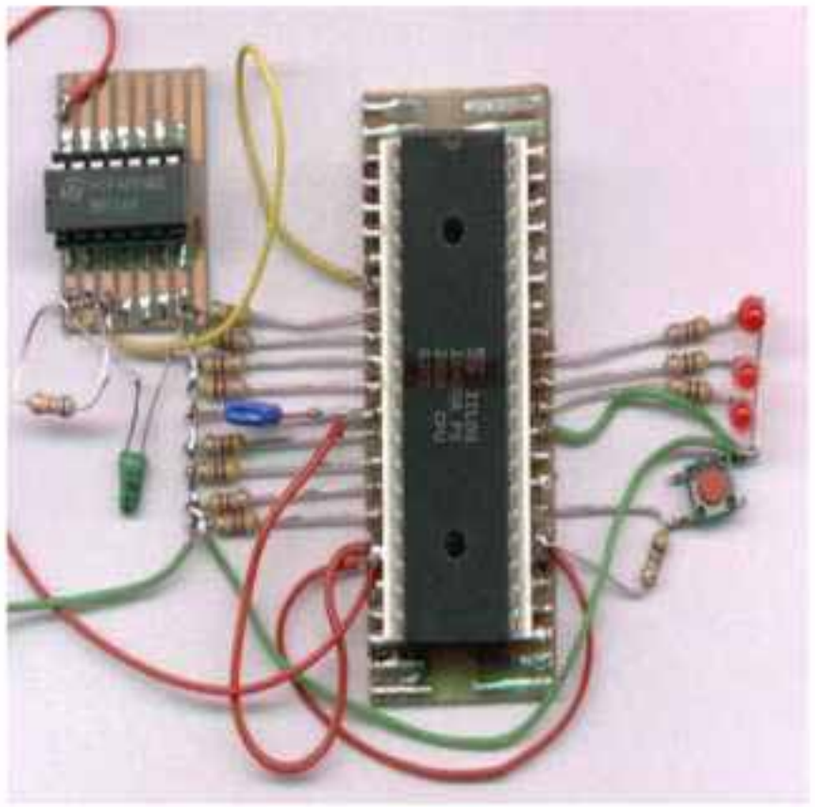
Is the SCN the body's master clock ?

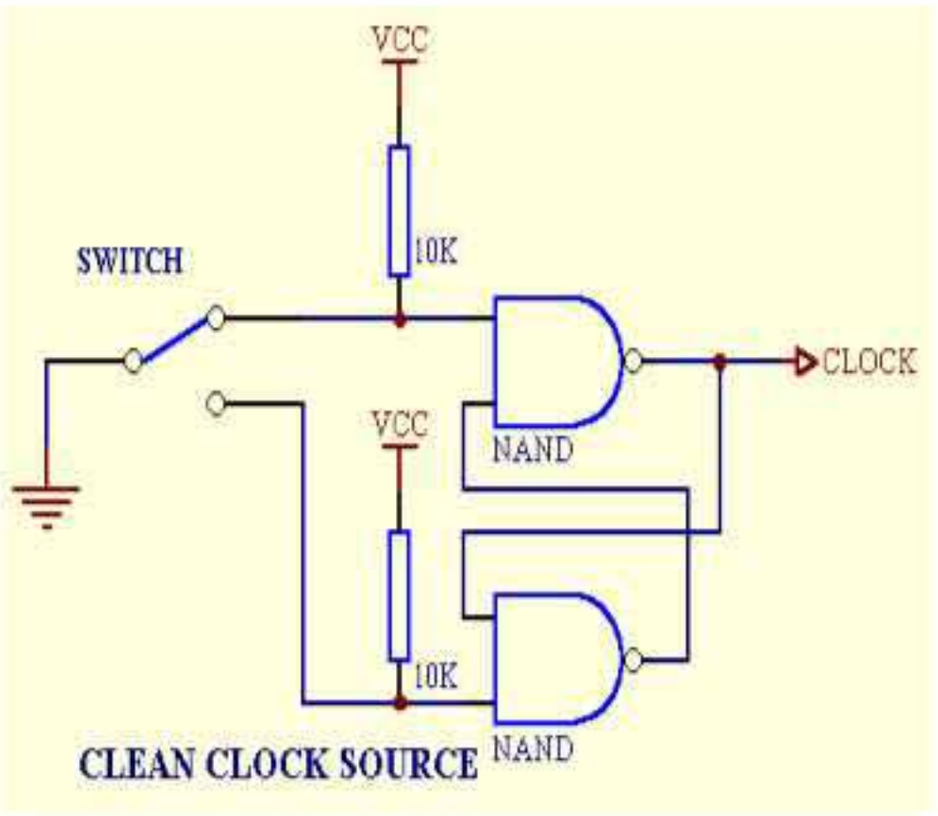
Not completely

It is more like a democratically elected government than a dictatorship

How ?

Central requirements are an input, an oscillator and an output

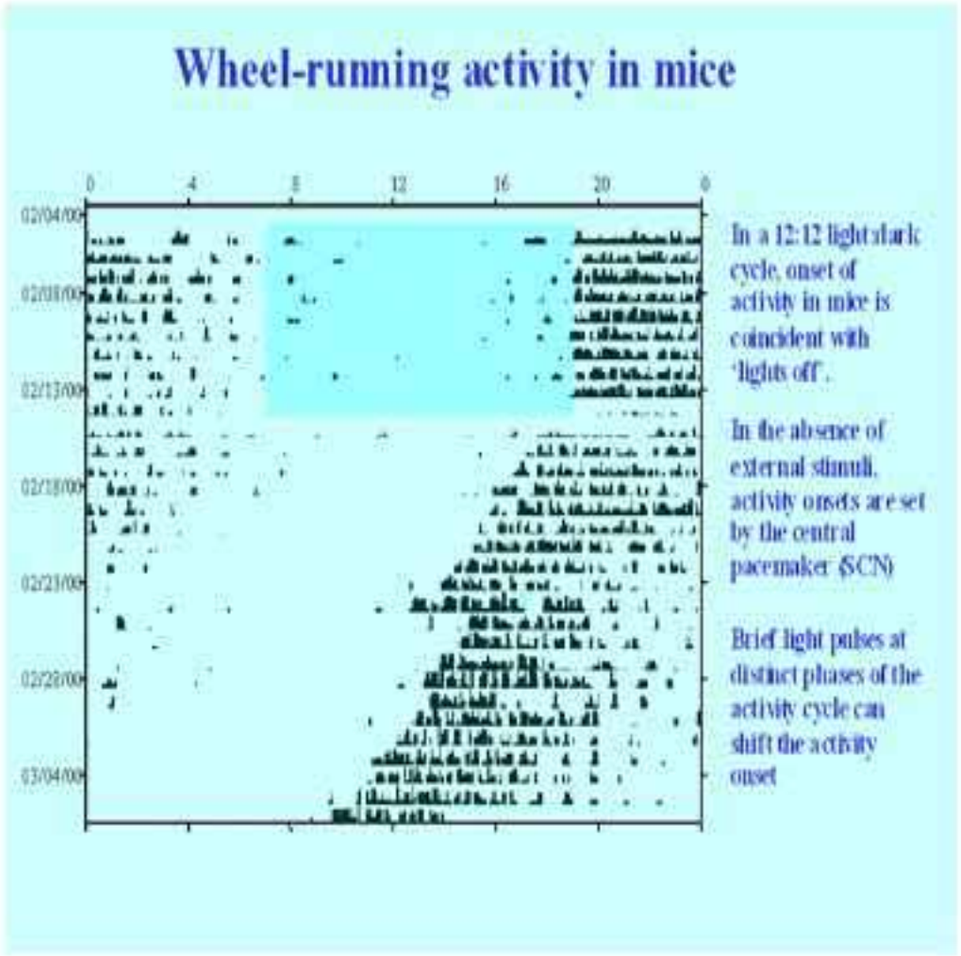




How ?

Central requirements are an input, an oscillator and an output

Circadian clocks need a 24h oscillation period

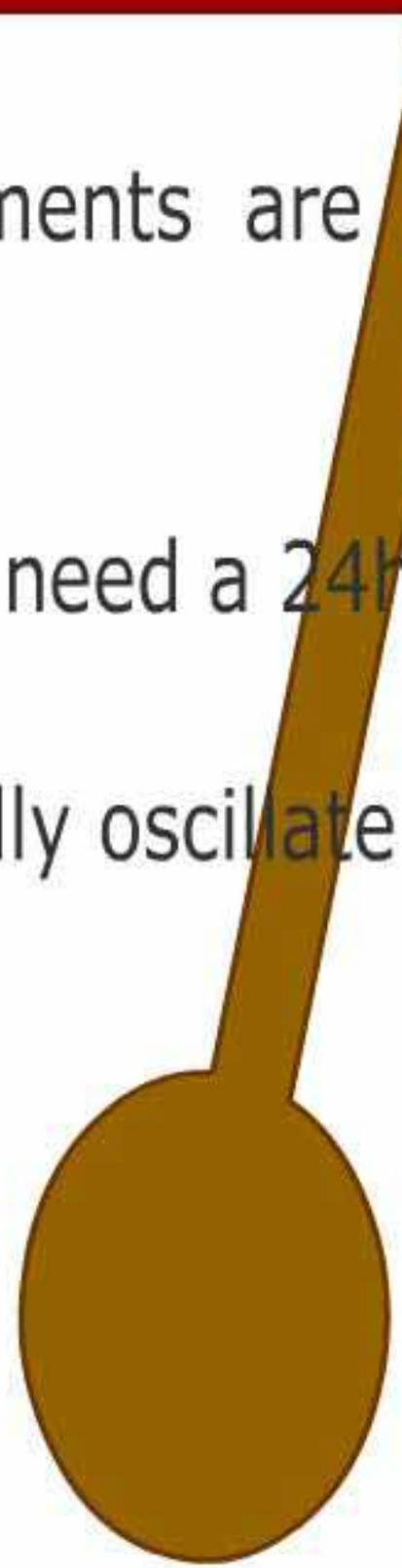


How ?

Central requirements are an input, an oscillator and an output

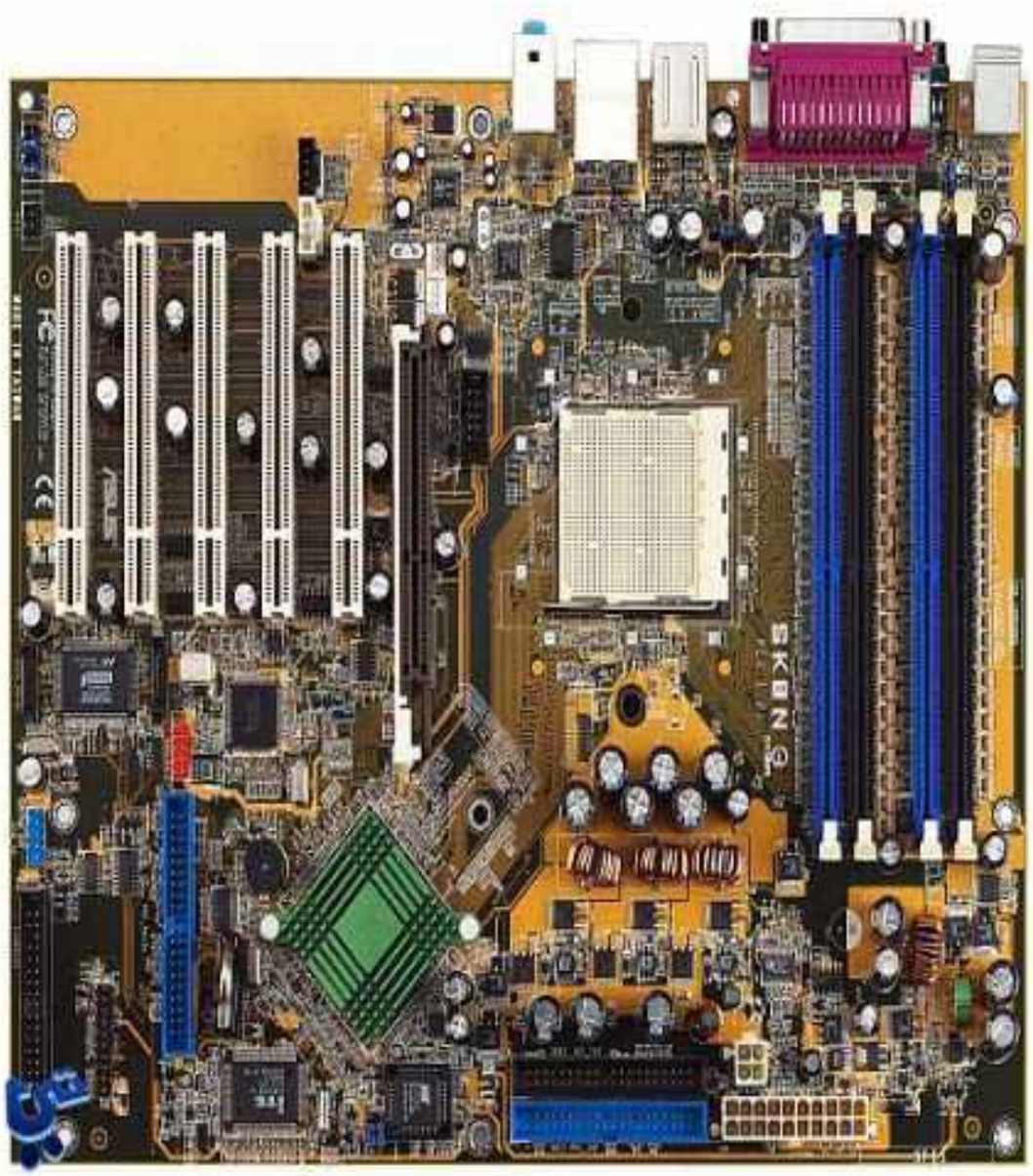
Circadian clocks need a 24h oscillation period

Pendulums usually oscillate at 1 cycle per second



How ?

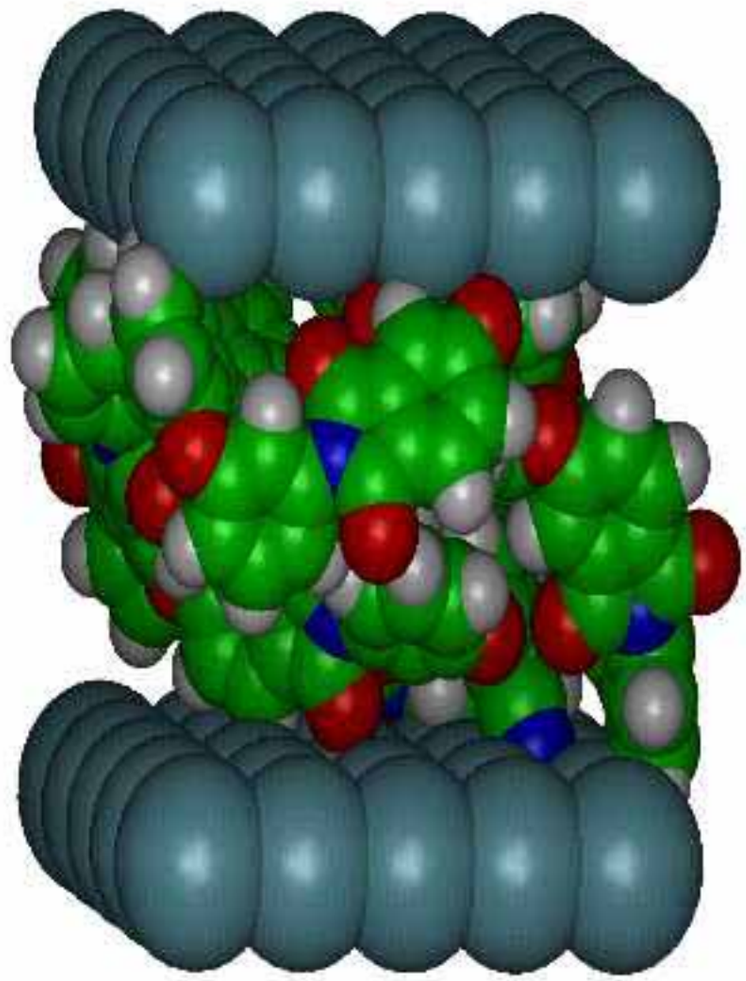
Computer clocks can oscillate at 10,000,000,000 (10^{10}) cycles per second



How ?

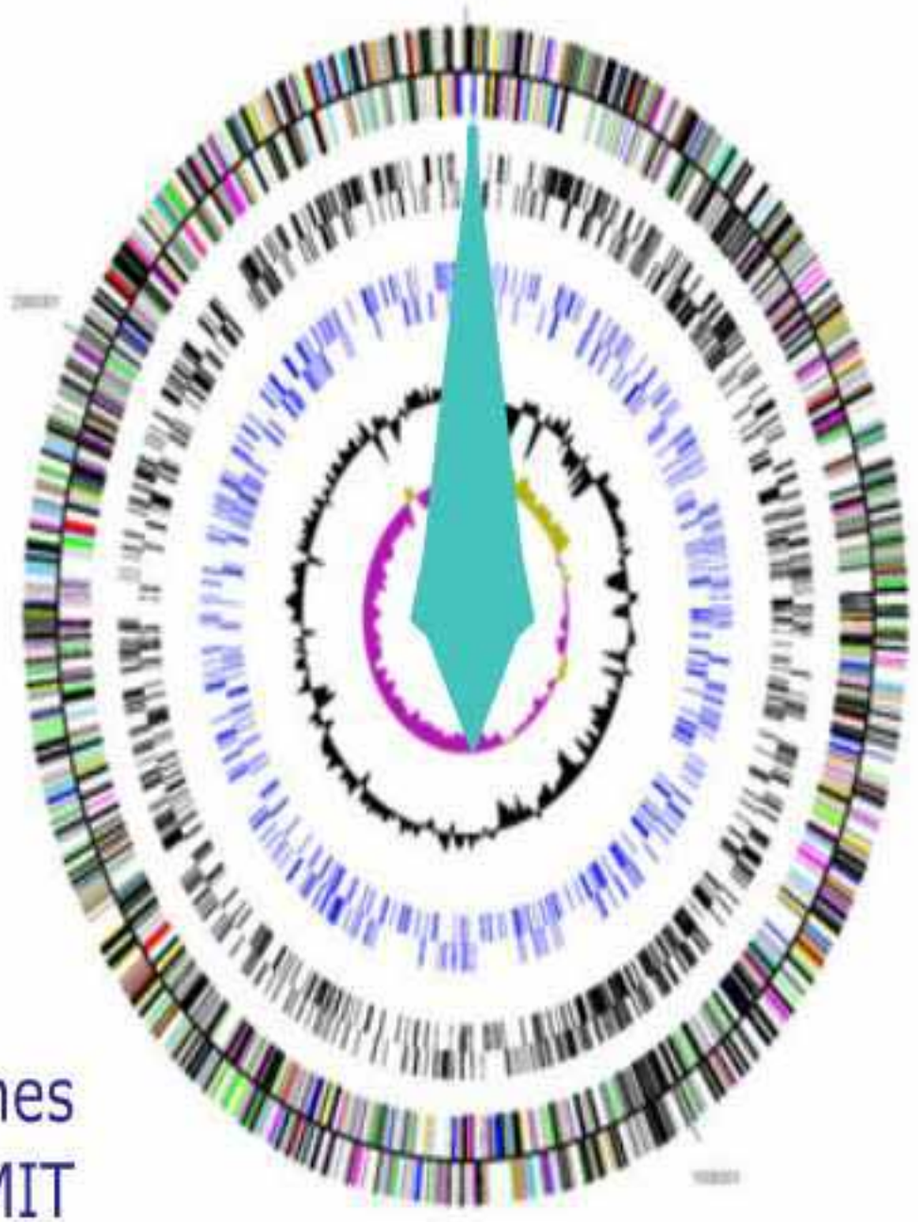
Computer clocks can oscillate at 10,000,000,000 (10^{10}) cycles per second

Atoms oscillate at 10,000,000,000,000,000 (10^{16}) cycles per second



How ?

What does a biological oscillator involving genes and proteins look like ?



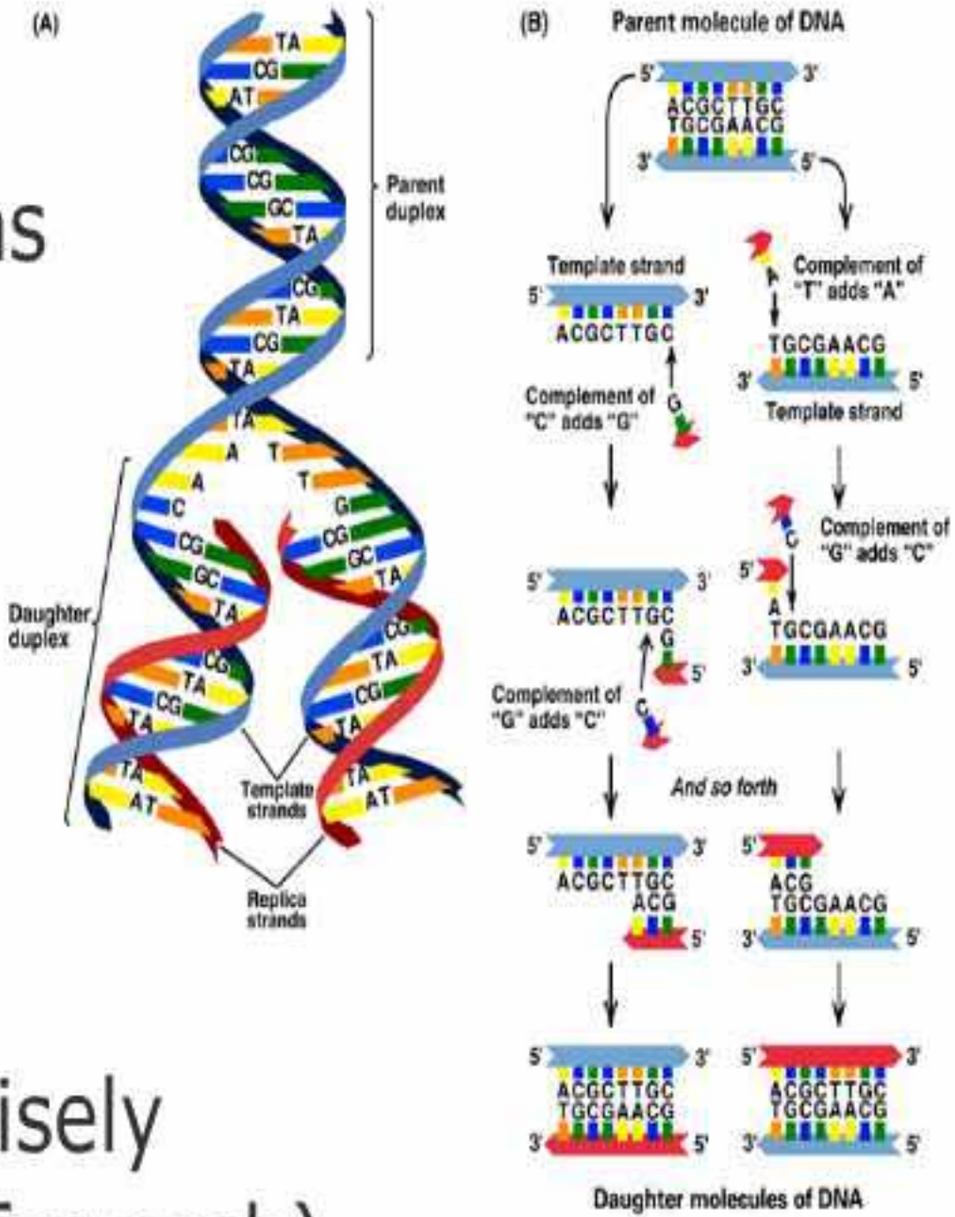
Plankton genes
MIT

How ?

What does a biological oscillator involving genes and proteins look like ?

Building blocks are genes and proteins

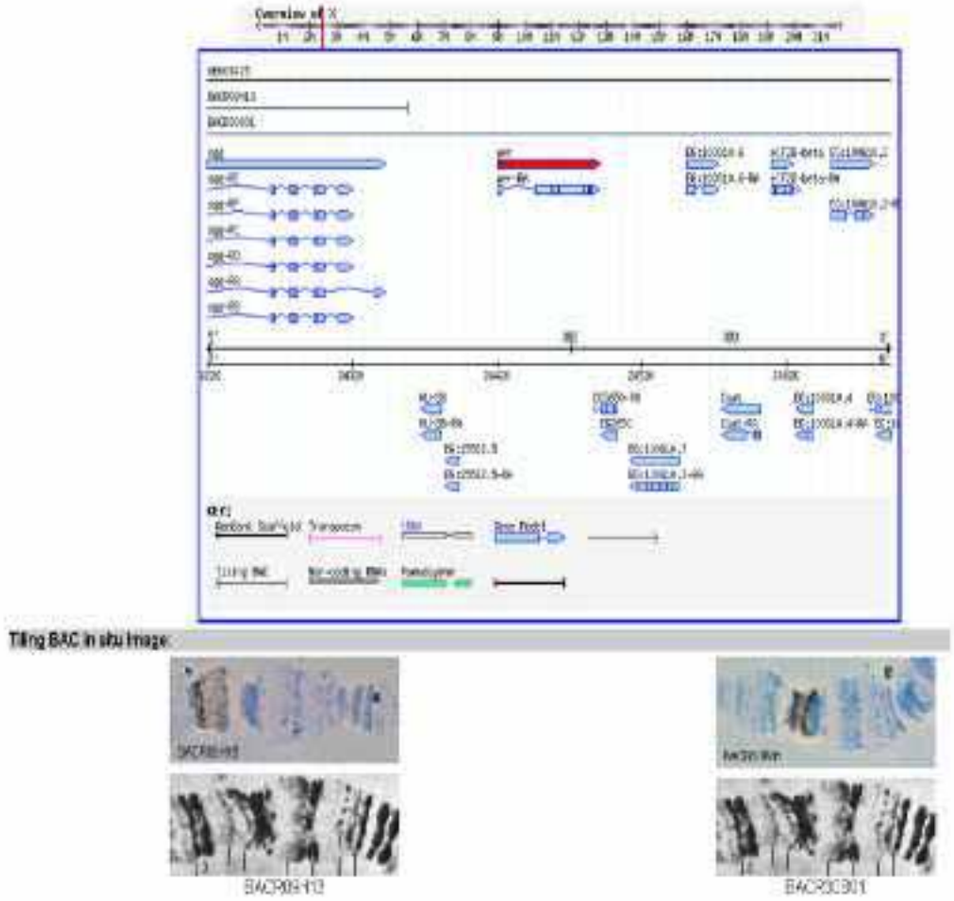
- Gene transcription
- Protein translation
- Protein dimerisation and binding
- Protein degradation
- FEEDBACK LOOPS



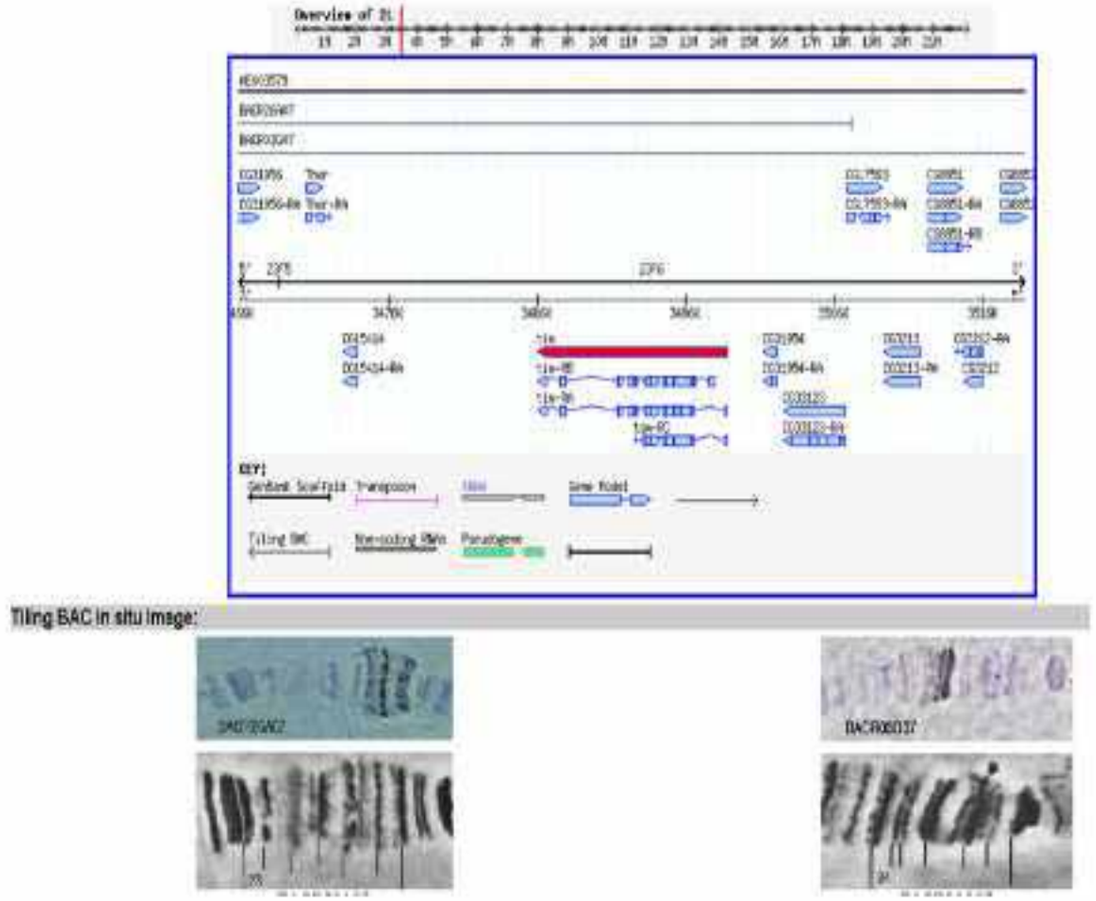
Each of these molecular steps is precisely temporally controlled (several hours for each)

How ?

The first clock genes were identified in drosophila mutagenesis screens



Per(iod) gene

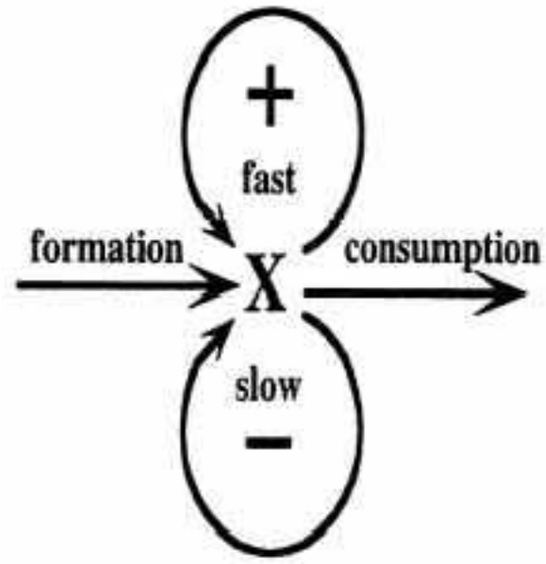


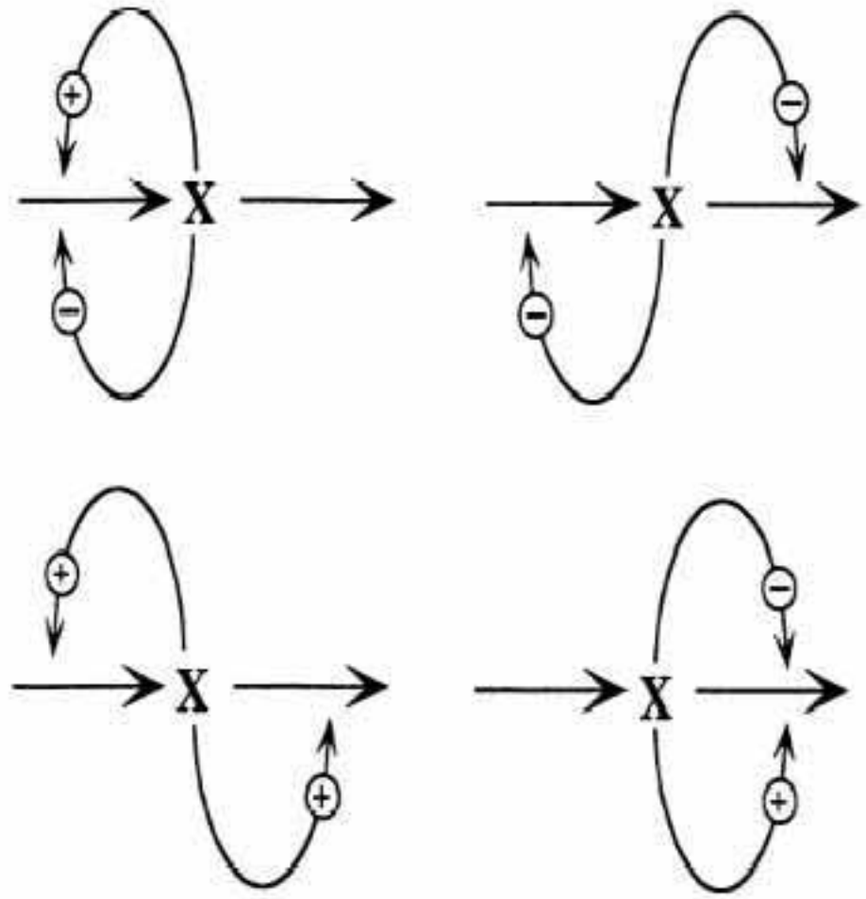
Tim(eless) gene

How ?

The bad news is that the molecular cogs and operators of biological clocks differ

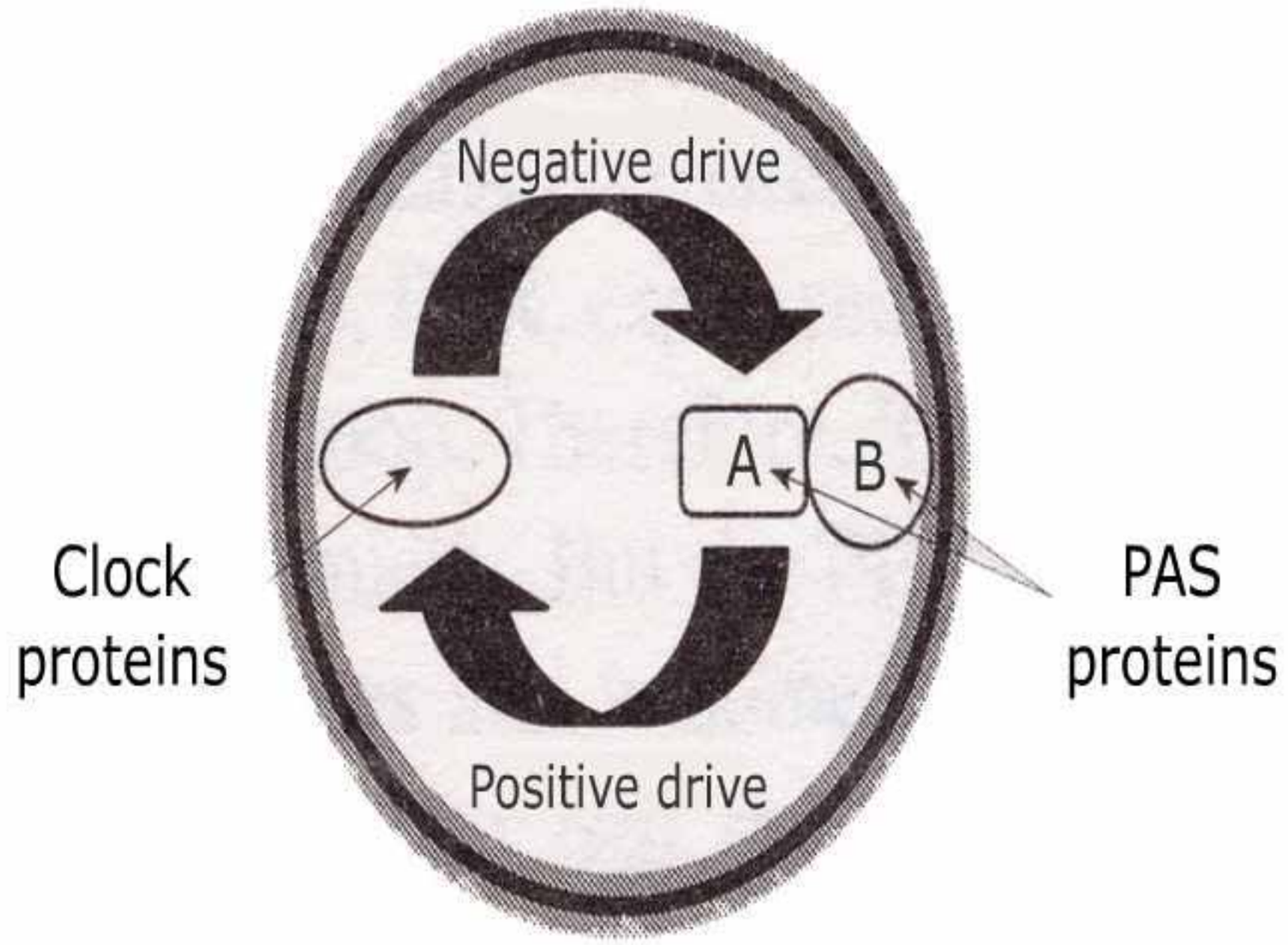
The good news is that they all seem to function with a positive and a negative feedback autoregulatory loop





How ?

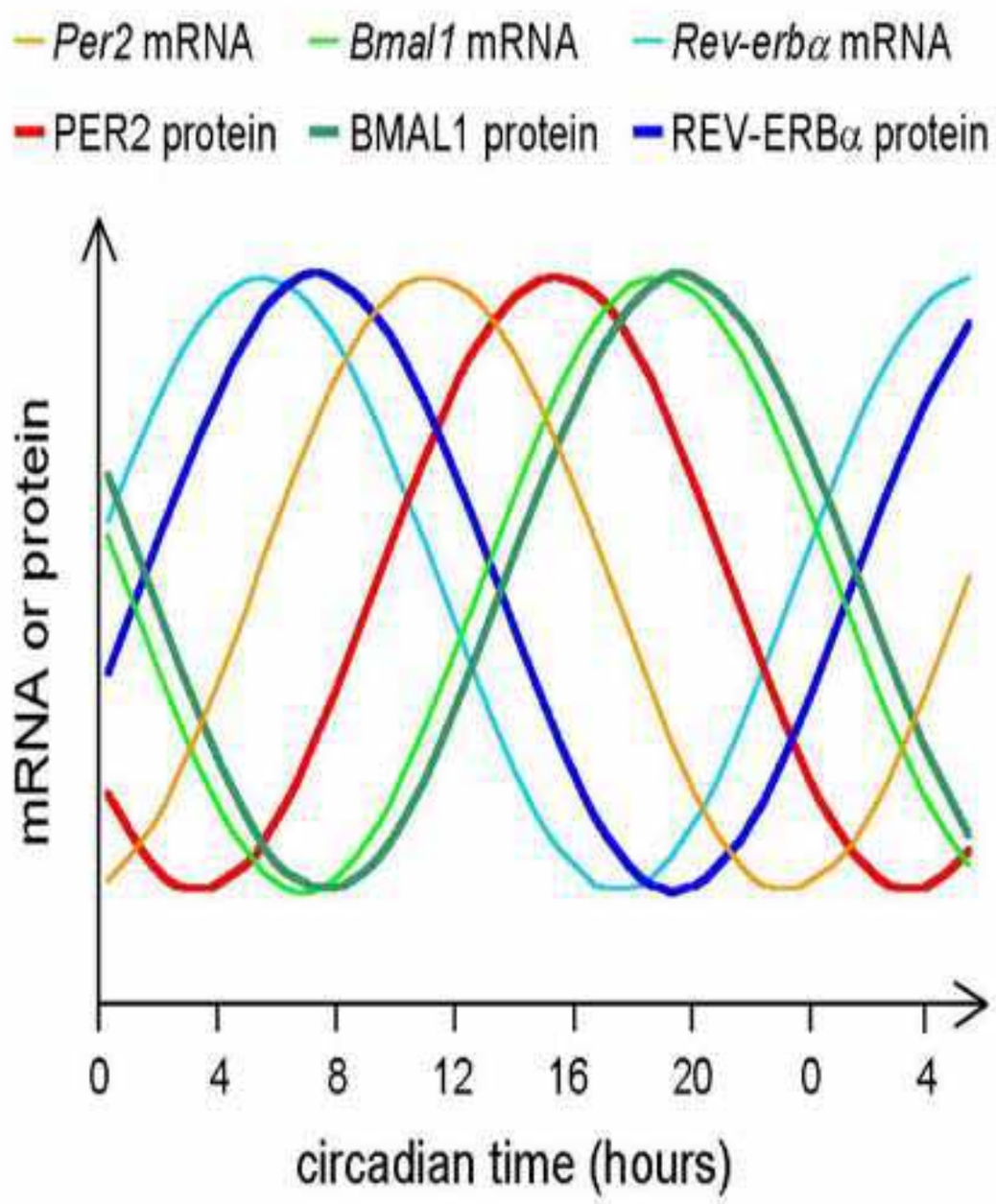
We now have a reasonable grasp of the key players



Conceptual circadian clock

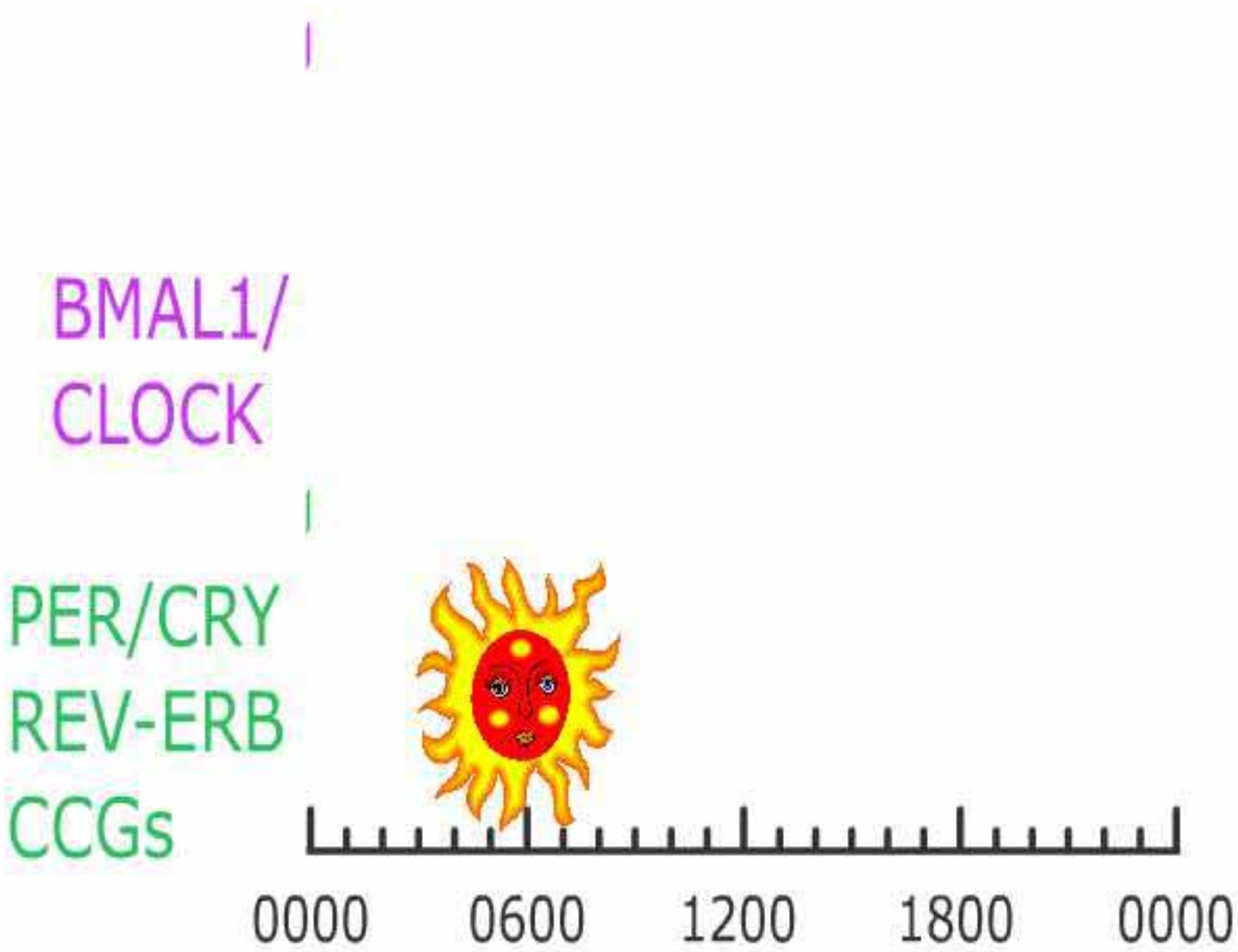
How ?

The mouse SCN clock



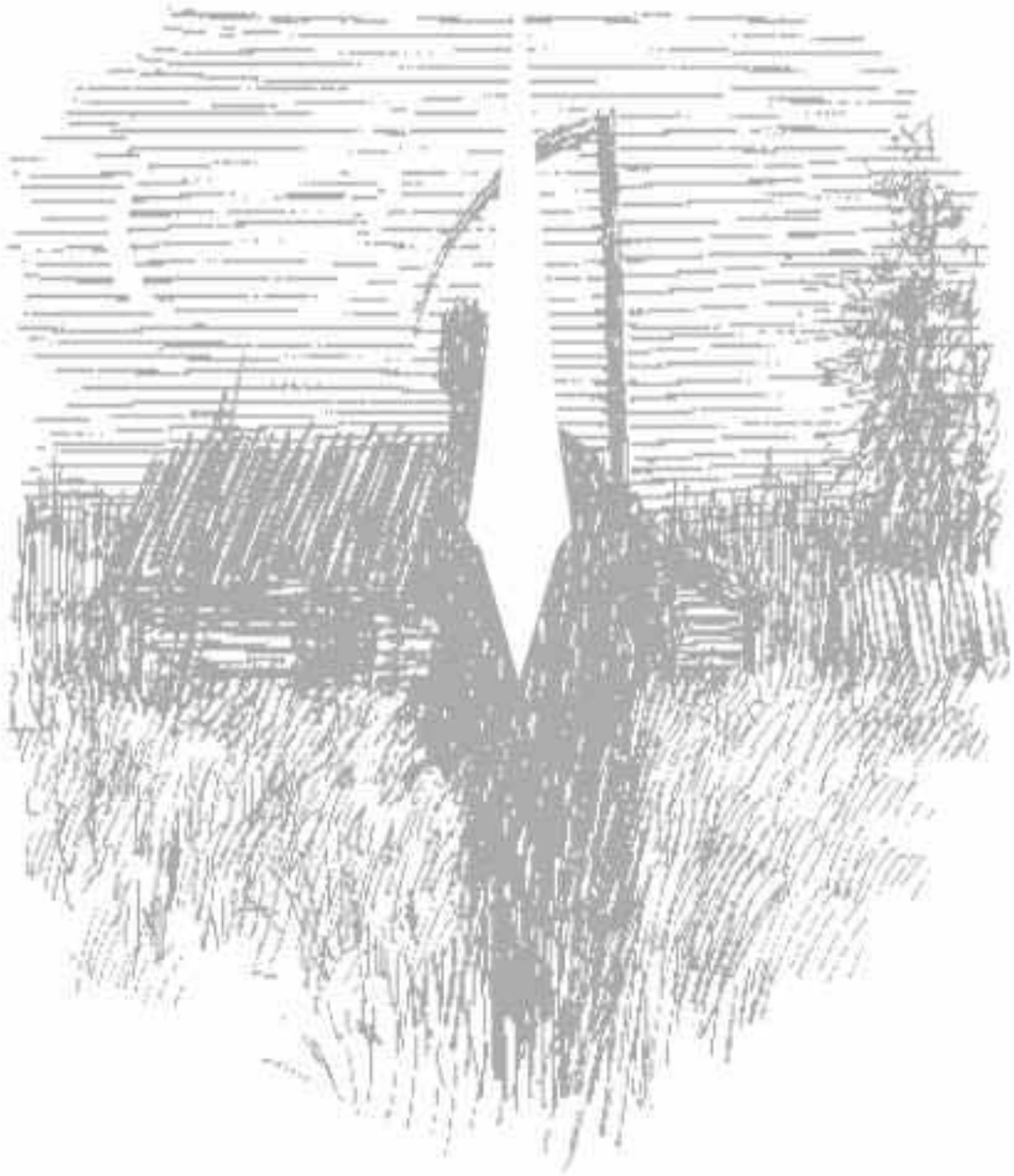
How ?

Entraining effects of light



Consequences of clock malfunctions

Malfunctioning biological clocks will at best make life miserable and at worst may even lead to death



Consequences of clock malfunctions

Jet lag - the problem

Human evolution did not cater for travel by air or even by boat

Every 1 hour time zone we cross takes 1 day for our clocks to reset

It takes 5 days to recover from
a trip from London to New York

Consequences of clock malfunctions

Why can symptoms get dramatically worse 2-3 days after travelling ?

Consequences of clock malfunctions

Why can symptoms get dramatically worse 2-3 days after travelling ?

Central and peripheral clocks recover at different rates and start opposing one another

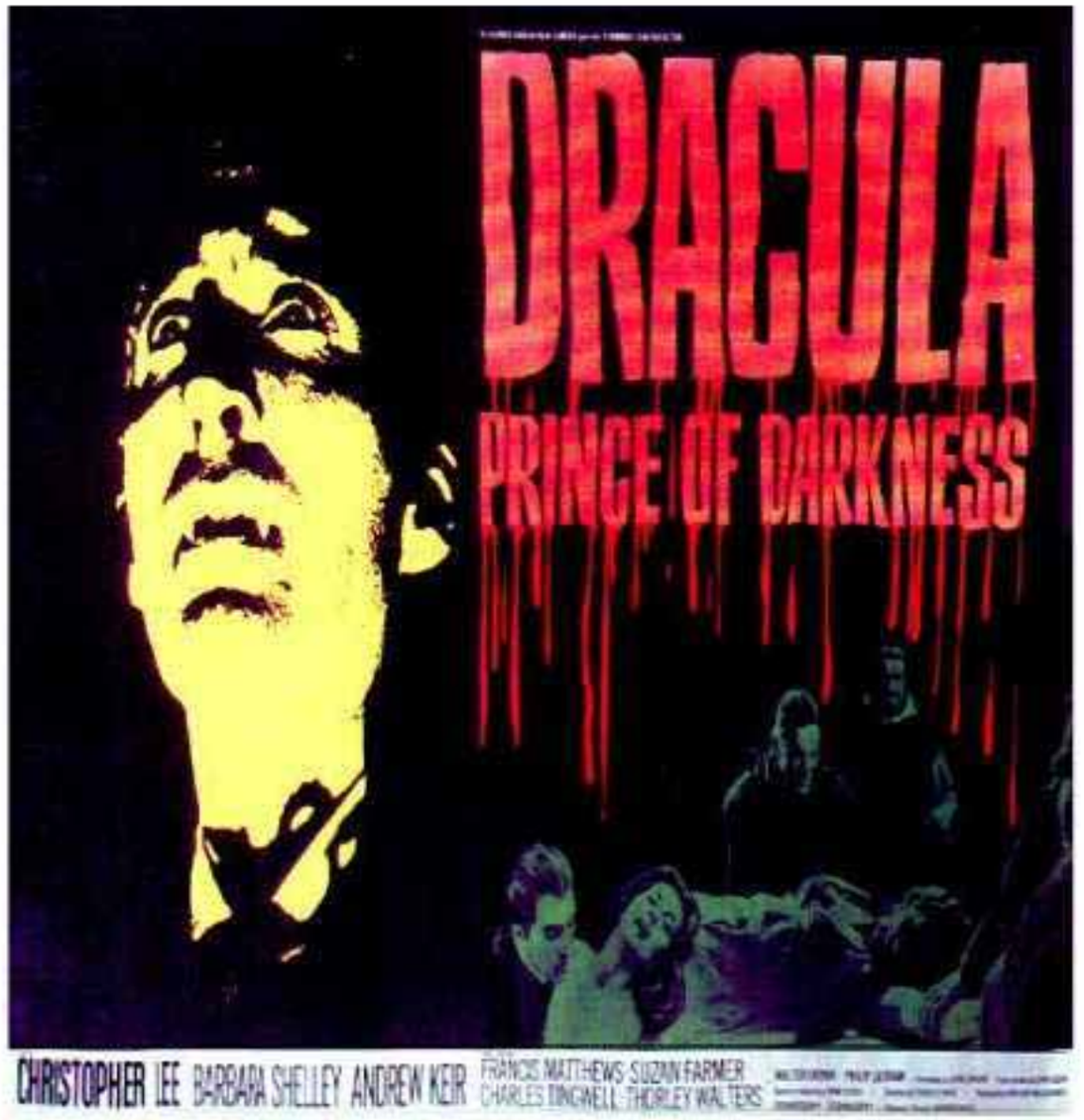
Consequences of clock malfunctions

Why is it worse travelling east than west ?

Our clocks seem to adjust better after a prolonged day than a shortened one

Jet-lag - possible ways to alleviate problems

Keep on home time and don't expose yourself to daylight at the wrong time

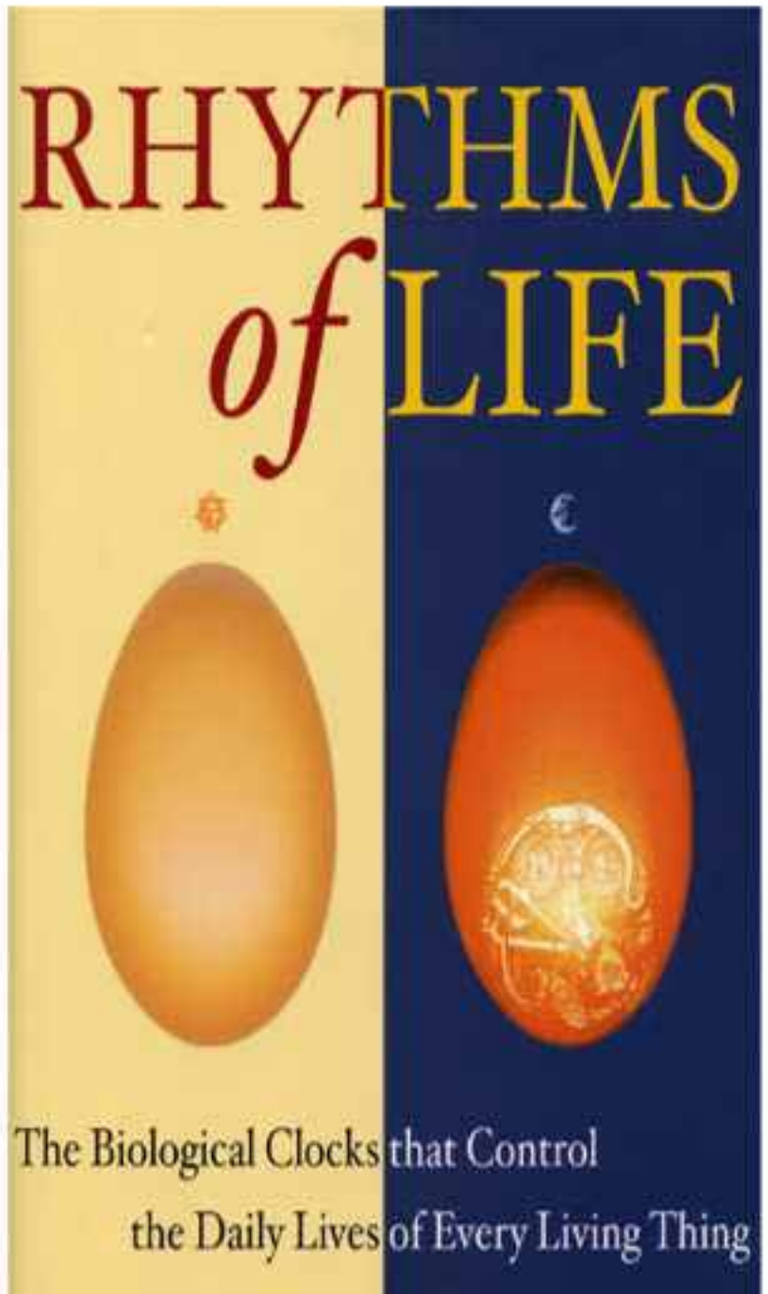


Jet-lag - possible ways to alleviate problems

Speed up adaptation to time zone changes by controlled exposure to light at different times of day

Foster and Kreitzman (2004)

Prior to body temperature minimum (4 am) light will delay your clocks, and after this it will advance them



Melatonin

Licensed for use in the USA but not the UK

Reduces jet-lag symptoms
if taken at the right time

Shift work

Our 24/7 society requires that many industries and services continue around the clock

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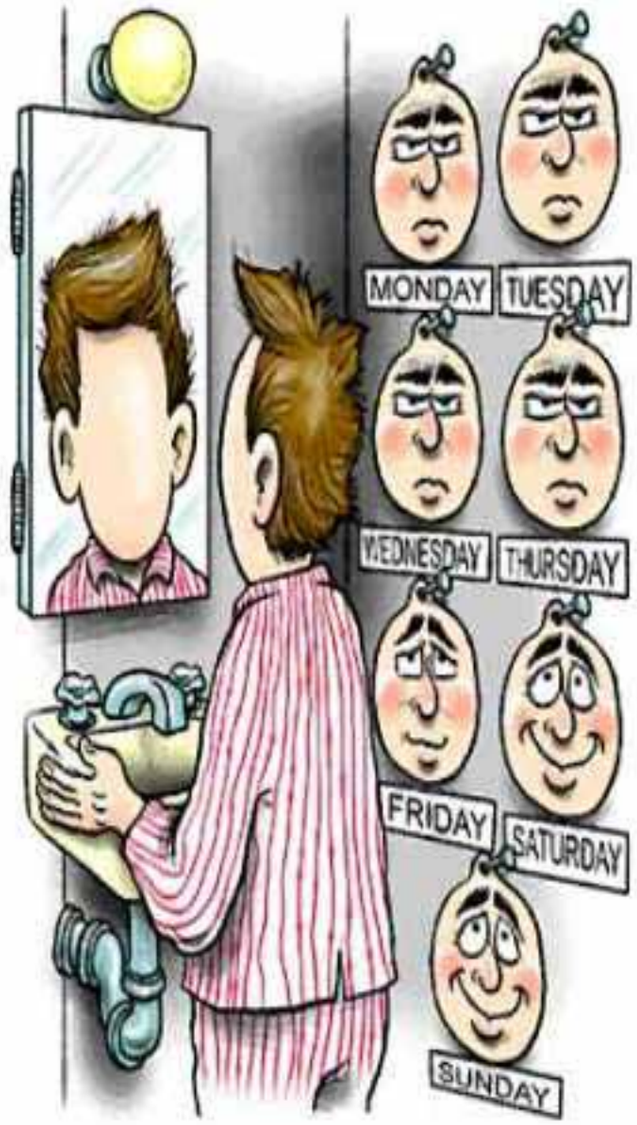
Our biological clocks can just about cope with a complete shift in our day and night cycles but it is not recommended

Shift work

Our 24/7 society requires that many industries and services continue around the clock

Our biological clocks can just about cope with a complete shift in our day and night cycles but it is not recommended

It takes a week or so to adapt to a night shift

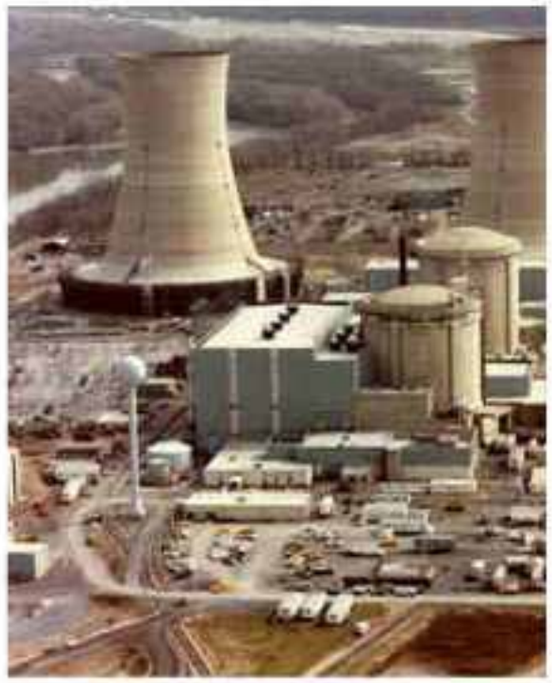


Shift work

Chopping and changing shift times is a nightmare for our biological clocks and often leads to states of chronic sleep deprivation

Shift work

What do disasters such as the Titanic, Estonia, Exxon Valdez, Three Mile Island, Chernobyl and Bhopal have in common ?



They all occurred at night when workers were on a night shift

Shift work

Workers on night-shifts have a 20% higher risk of injury than on day shifts

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After four night shifts a worker has a 50% higher risk of a road accident

Shift work

Workers on night-shifts have a 20% higher risk of injury than on day shifts

After four night shifts a worker has a 50% higher risk of a road accident

Higher risk of cancer and cardiovascular diseases

CANCER RESEARCH UK

British Heart Foundation

Strategies for dealing with shift work

No agreed best policy on this

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It is generally best to spend 1 week or more on each type of shift

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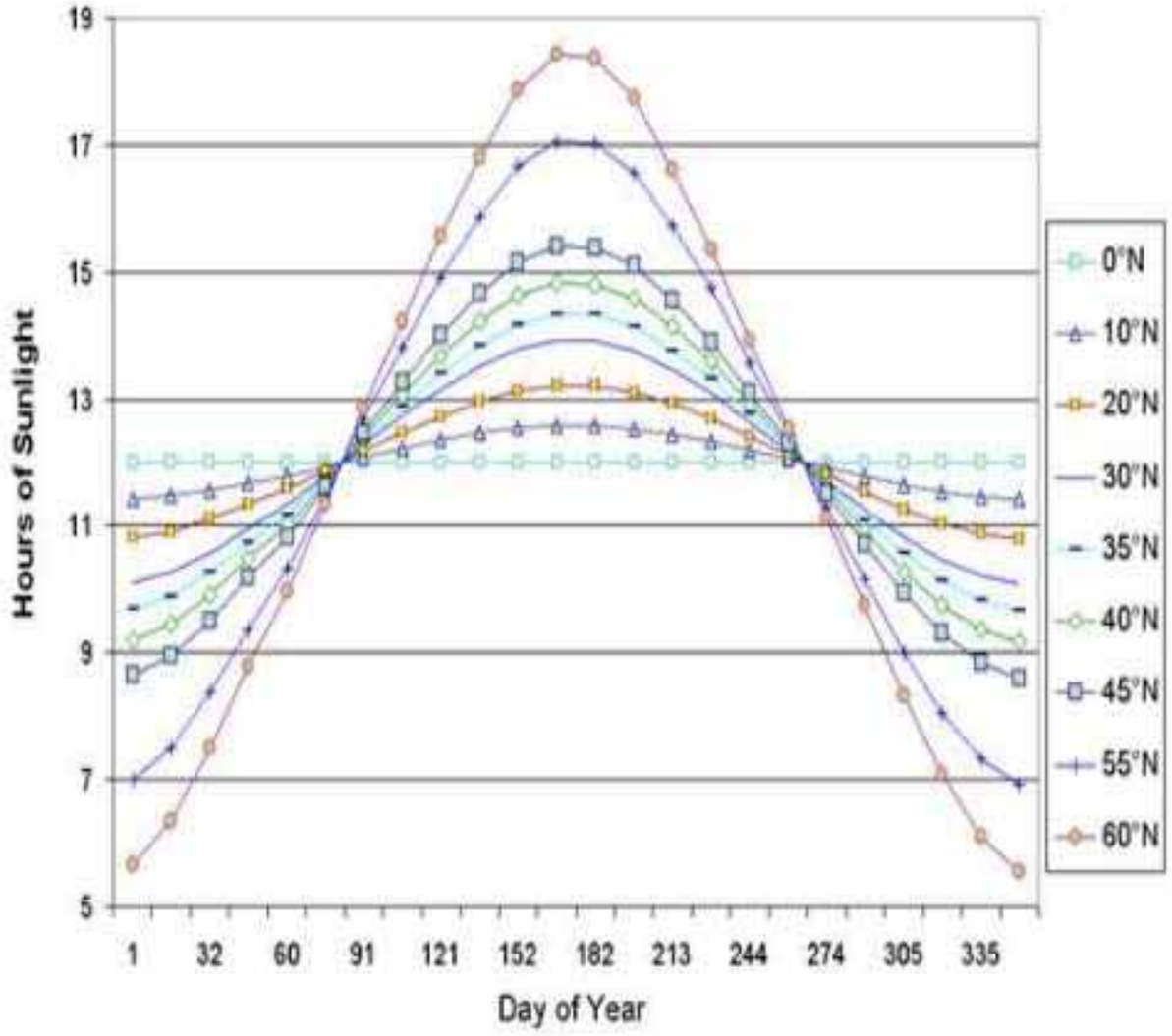
It is generally best to spend 1 week or more on each type of shift

Weekends are a problem however !

Speed of shift changes and length of shifts can make a difference

Seasonal affective disorder (SAD)

Our human circadian pacemaker can detect seasonal changes in day length



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This can have subtle effects on our behaviours, emotions, physiology and biochemistry

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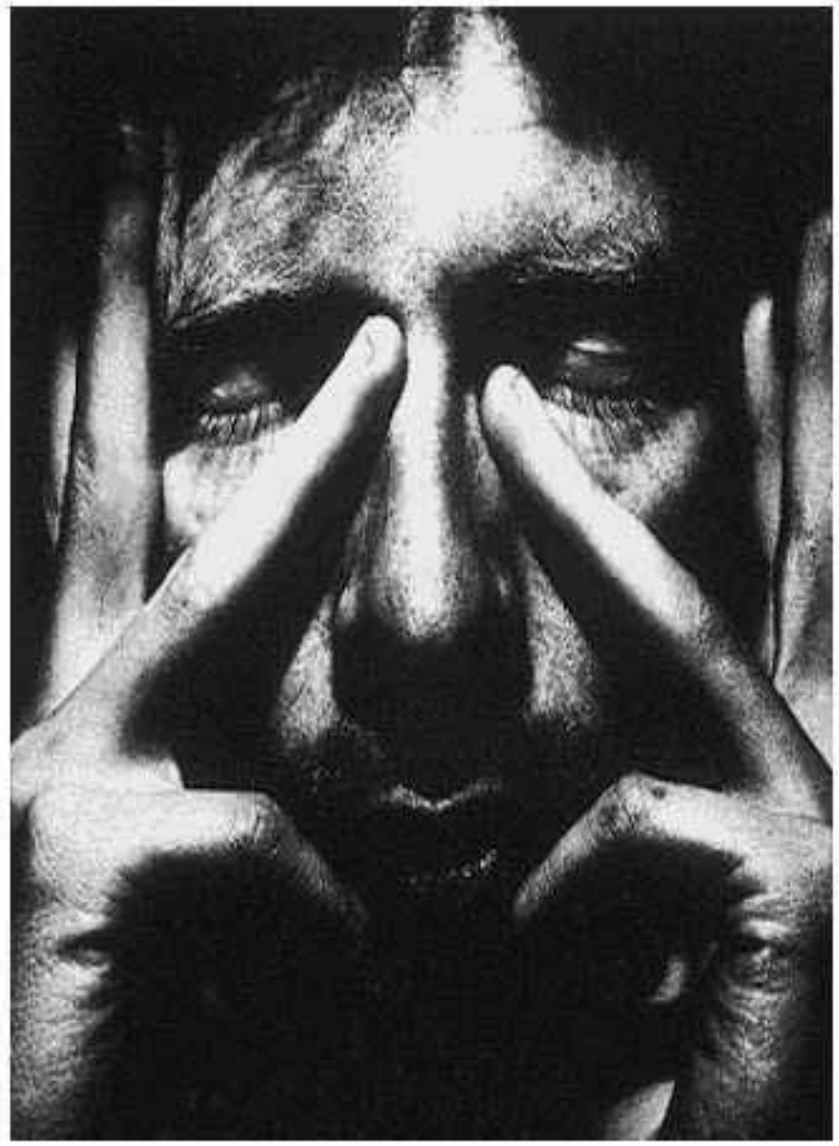
This can have subtle effects on our behaviours, emotions, physiology and biochemistry

For 3% of people in the UK, and more in Northern latitudes, shortening days cause a profound depression



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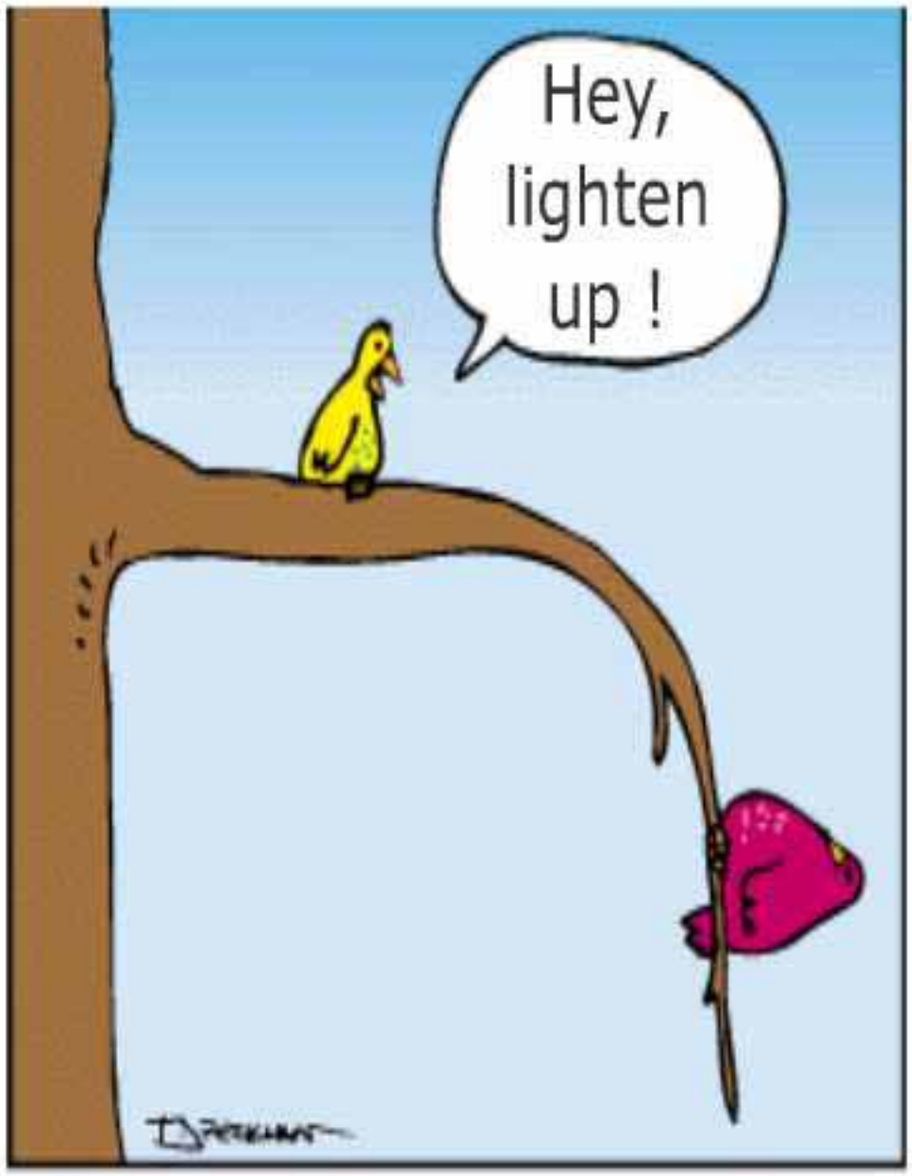
They crave carbohydrates and may put on 5-15 kilograms in weight



Seasonal affective disorder (SAD)

Individuals become seriously depressed, socially withdrawn, lethargic and even suicidal

They crave carbohydrates and may put on 5-15 kilograms in weight

Symptoms largely disappear with lengthening days

It resembles hibernating animal species - lethargy and weight gain

Seasonal affective disorder (SAD)

Ancestral signal to become inactive or migrate south ?

Treatments for SAD

Exposure to high intensity light sources that resemble normal day light

Outside In lightboxes

Other lightboxes

Treatments for SAD

Exposure to high intensity light sources that resemble normal day light

2500 lux (a cloudy day) for around 45 minutes between 3.30 and 8 am

Outside In lightboxes

Other lightboxes

Old age

Old Father Time makes our biological time clocks erratic

Sleep duration is less and we spend less time in deep stages

Almost all other rhythms become less pronounced

We really are less affected by the ups and downs of life

Old age

Potential remedies:

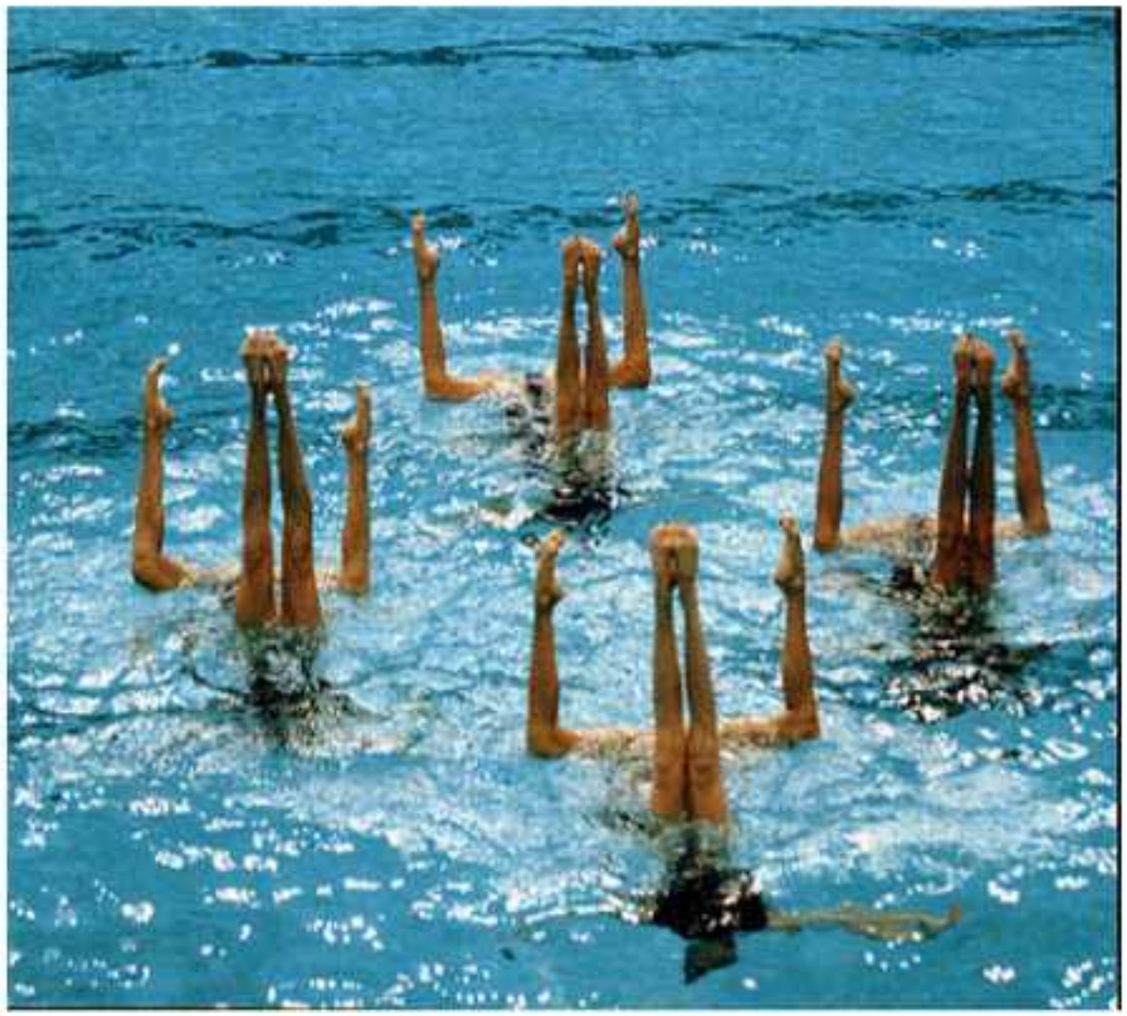
Don't mess your clocks about too much when you are young

Old age

Potential remedies:

Don't mess your clocks about too much when you are young

Try to keep to regular lifestyle schedules



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Melatonin ?

Old age

Potential remedies:

Don't mess your clocks about too much when you are young

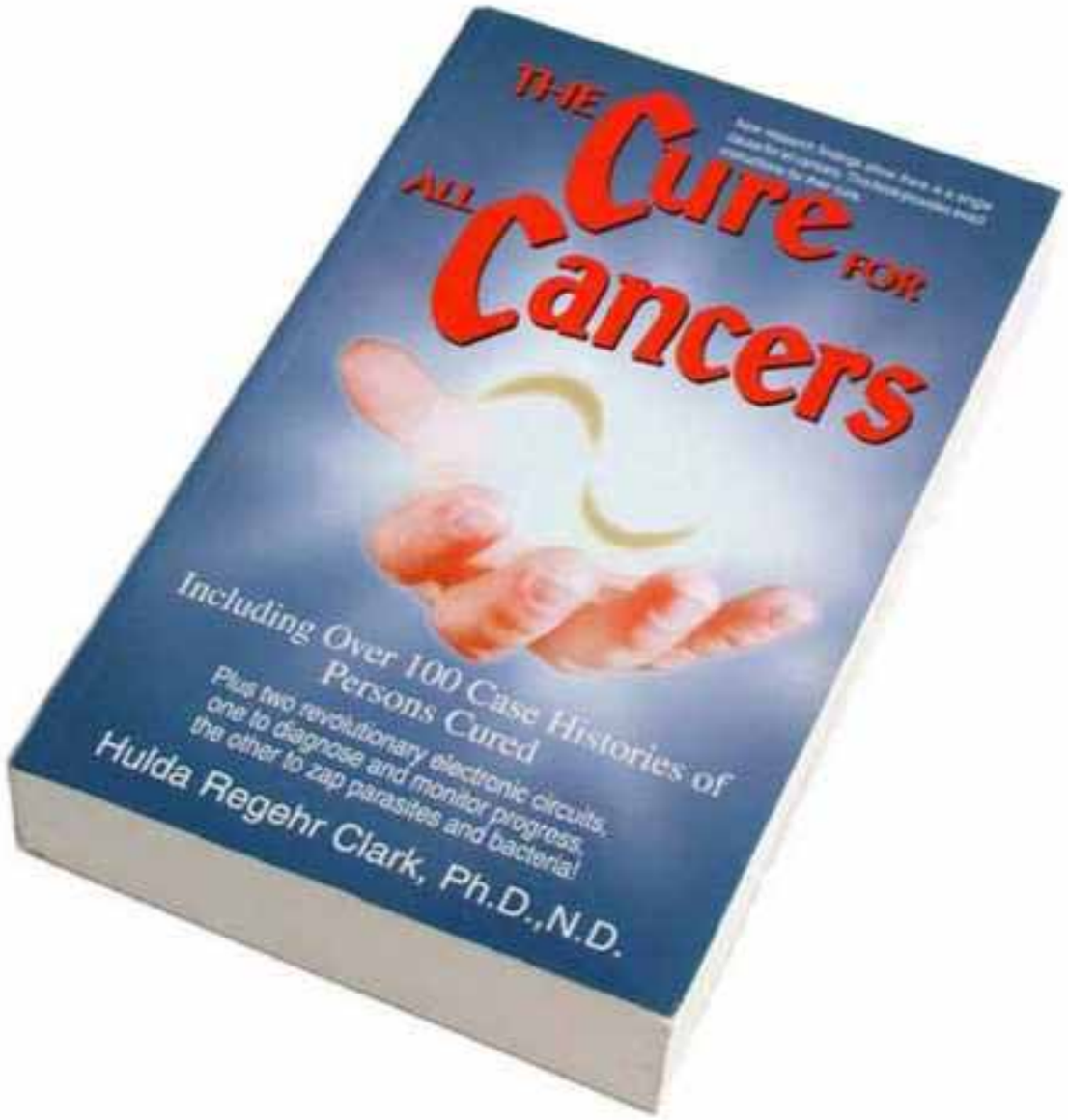
Try to keep to regular lifestyle schedules

Melatonin ?

Get new clocks !

Cancer

Relationship between clock genes and cancer is now well established



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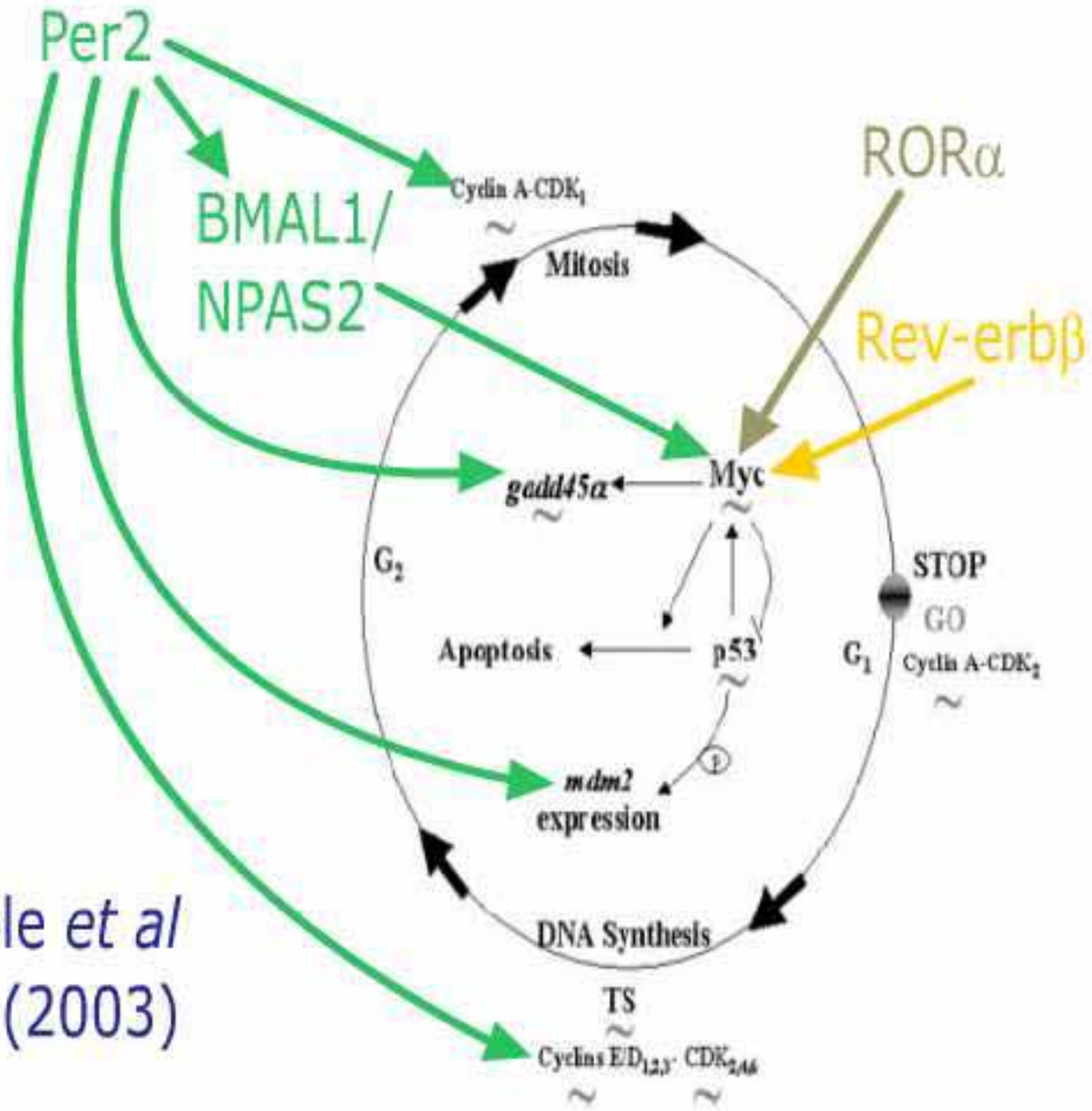
Relationship between clock genes and cancer is now well established

All cell cycle phases controlling cell division are influenced by clock genes



adapted from Canaple *et al*
Cancer Research (2003)

Cancer

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Tumours in mice without a brain clock grow more quickly

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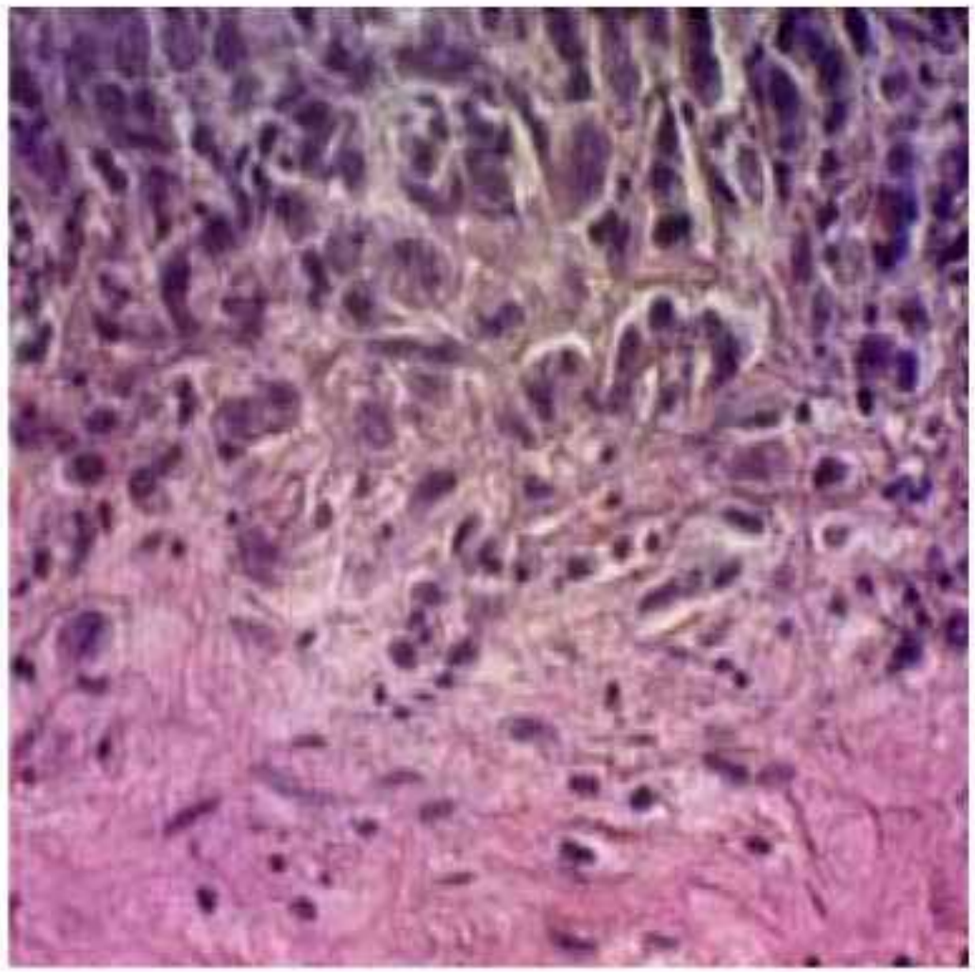
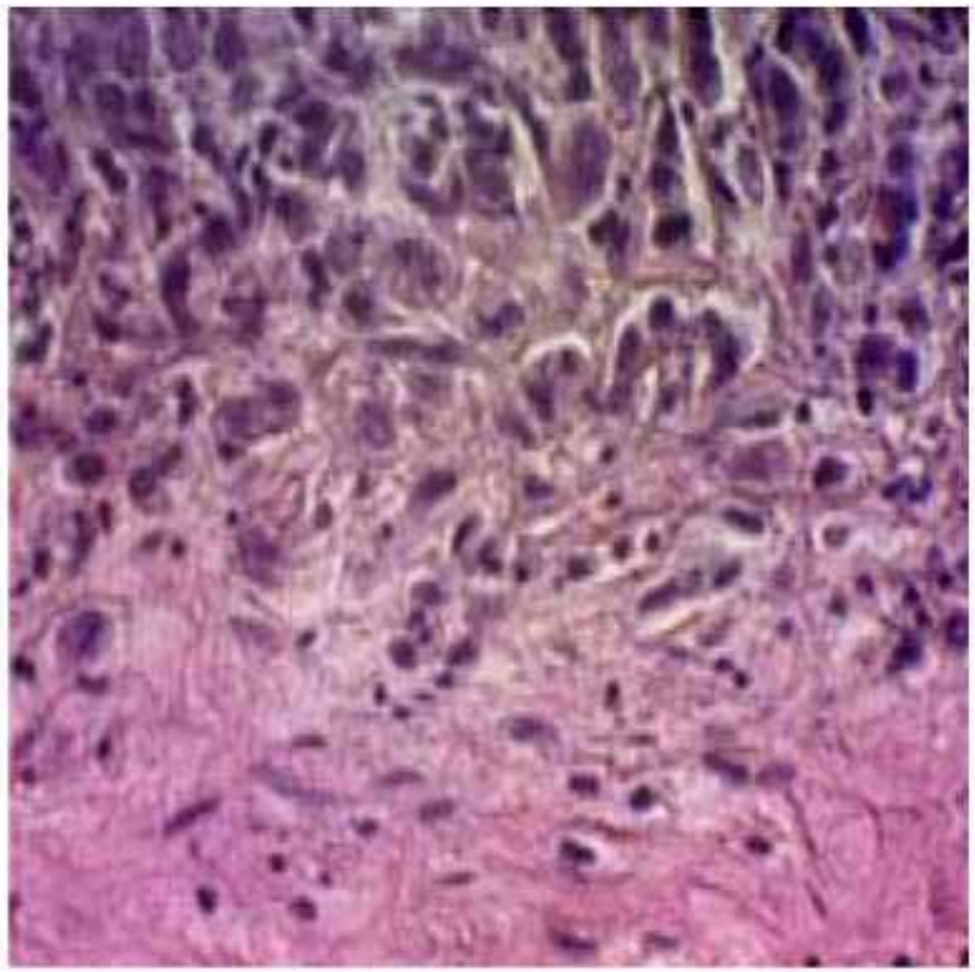


Tumours in mice without a brain clock grow more quickly

Mice lacking the per2 clock gene develop more spontaneous tumours

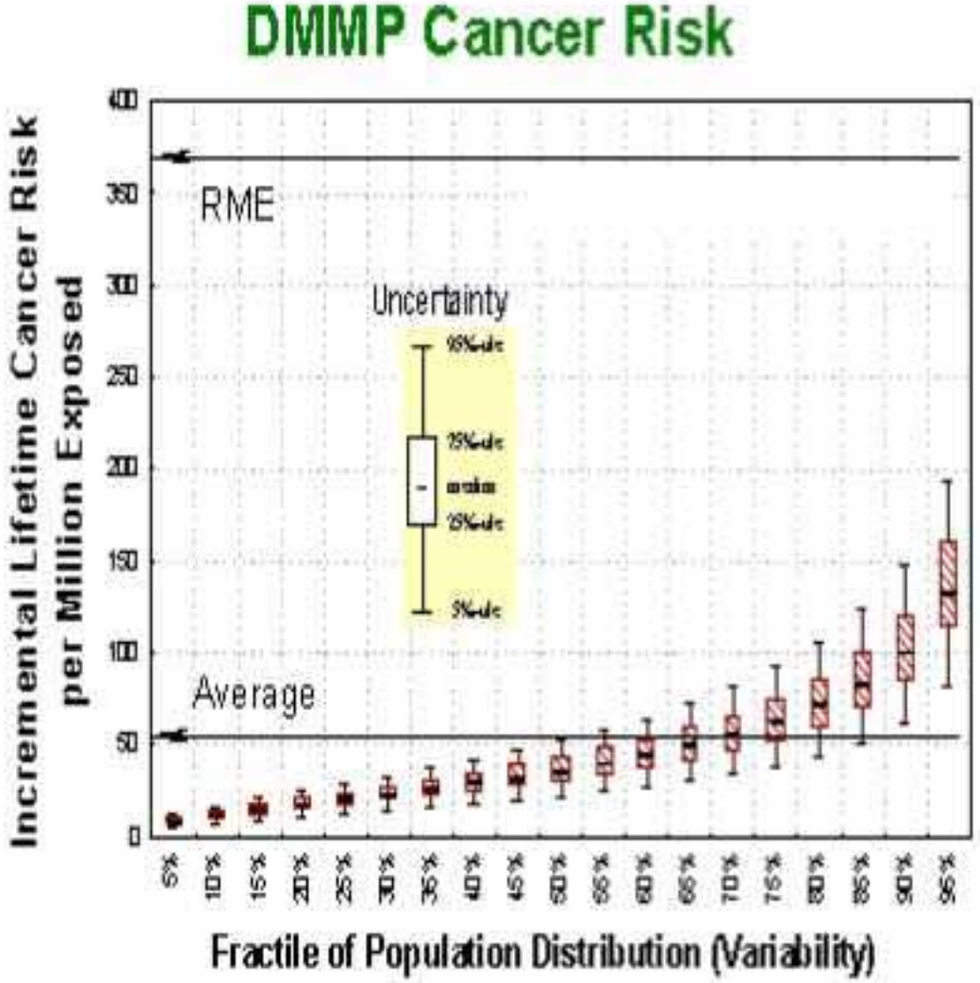
Conclusion: our biological clocks and clock genes are tumour suppressors



Cancer

Conclusion: our biological clocks and clock genes are tumour suppressors

This may be why frequent long-distance travel and shift work increase cancer risk



Cancer

Conclusion: our biological clocks and clock genes are tumour suppressors

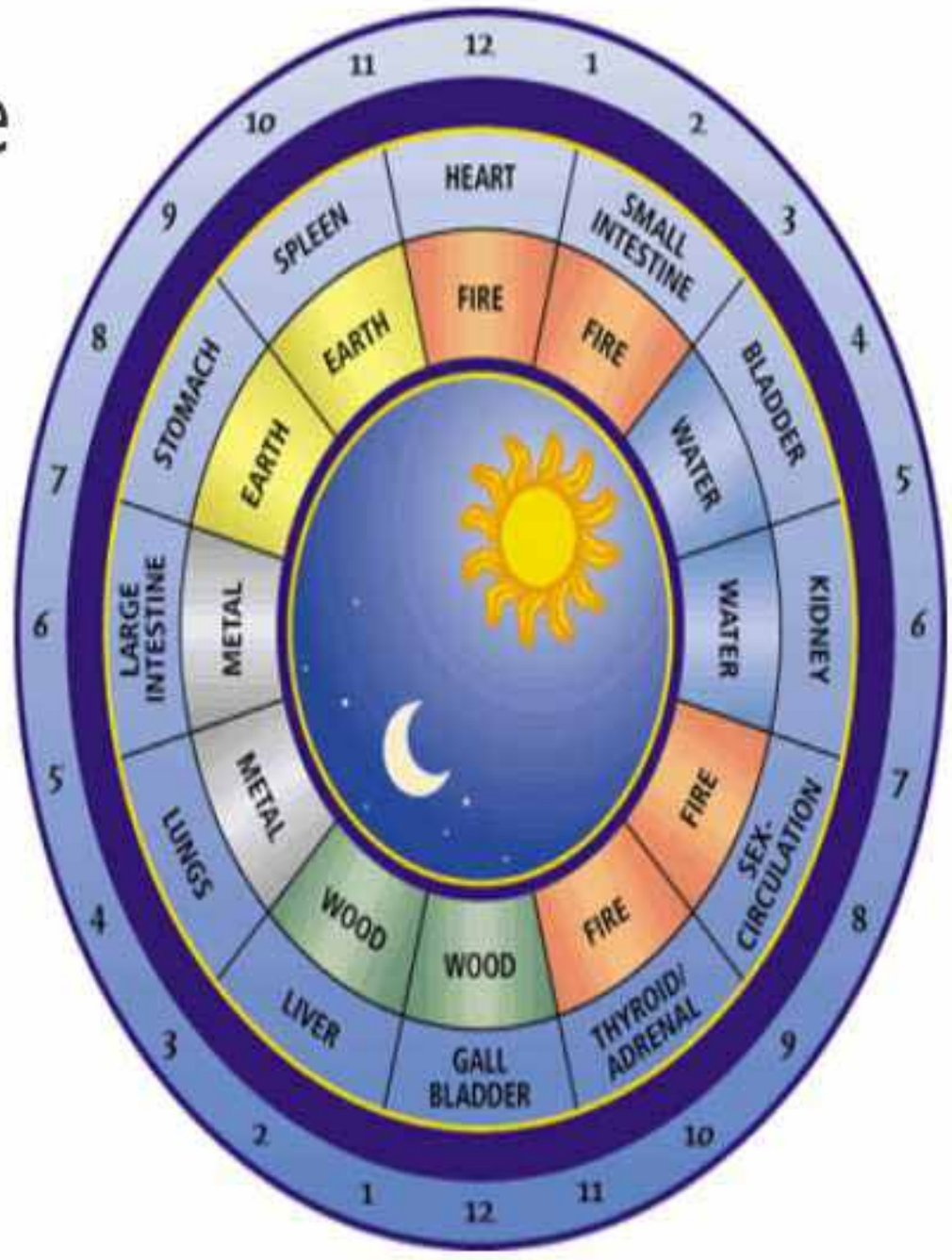
This may be why frequent long-distance travel and shift work increase cancer risk

Cancer cells also have clocks but these are out of phase with normal cells

It's time for your medicine dear

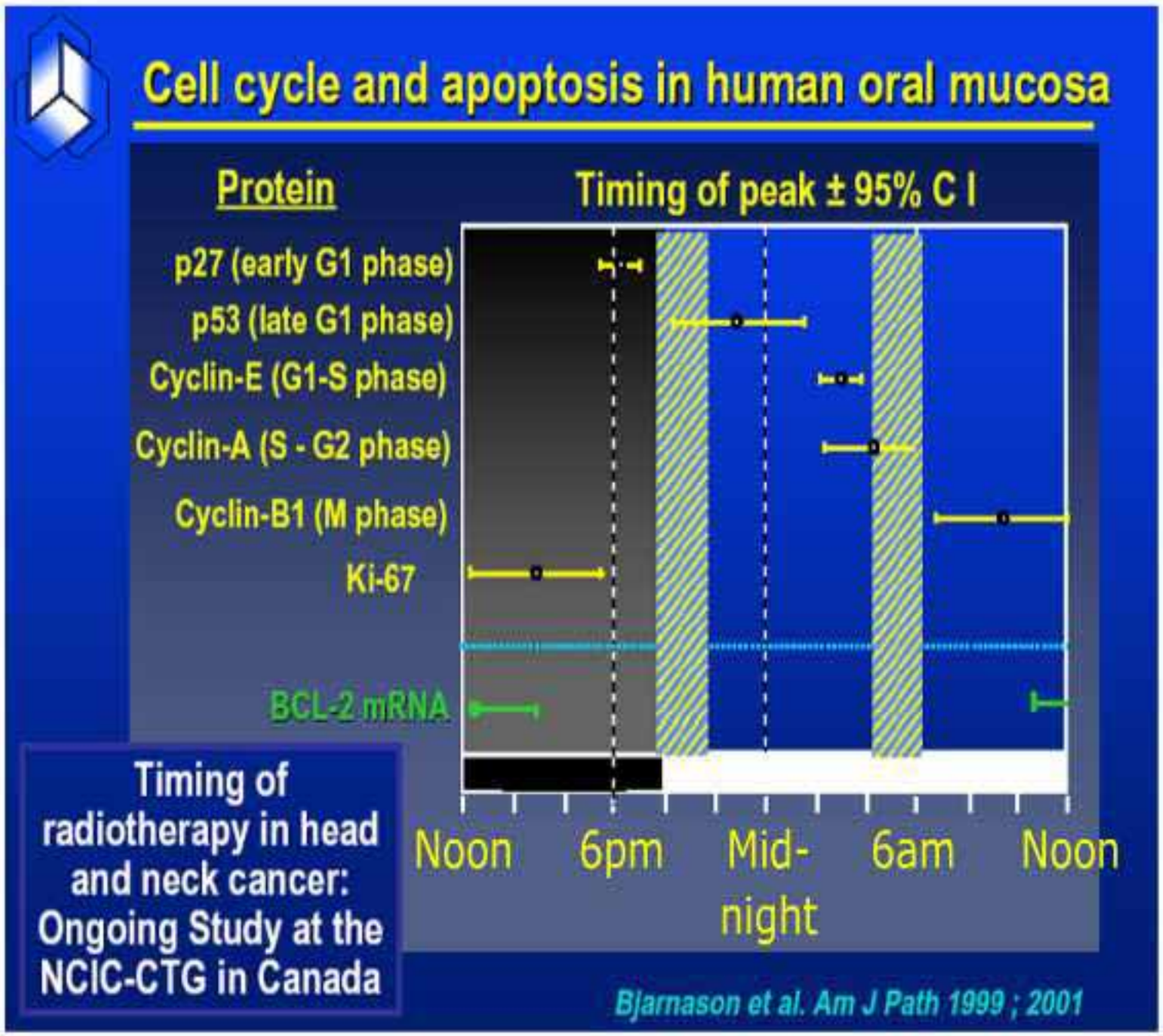
Chronotherapy

When you give a medicine may be almost as important as what it is



Cancer chemotherapy

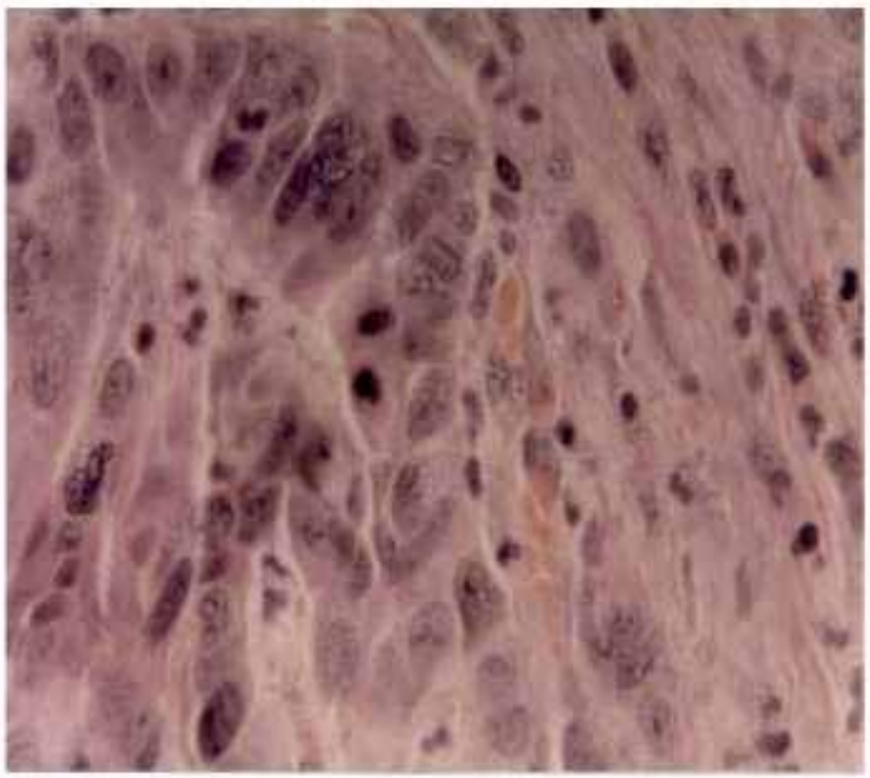
Timing doses to coincide with vulnerable S and G2 phases of dividing cancer cells

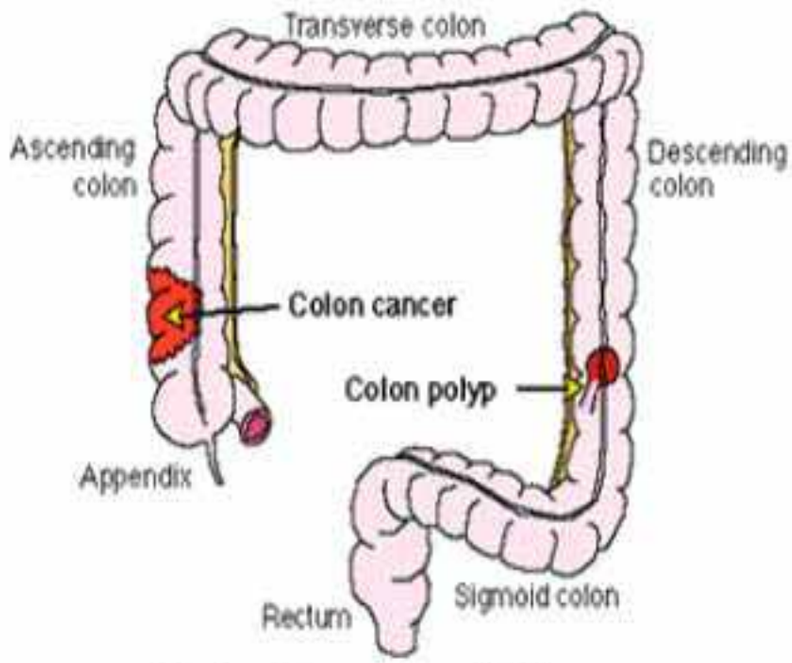


Cancer chemotherapy

Timing doses to coincide with vulnerable S and G2 phases of dividing cancer cells

Colon cancer - 40% higher dose, 3-fold increase in >50% tumour shrinkage (Levi et al 2001)





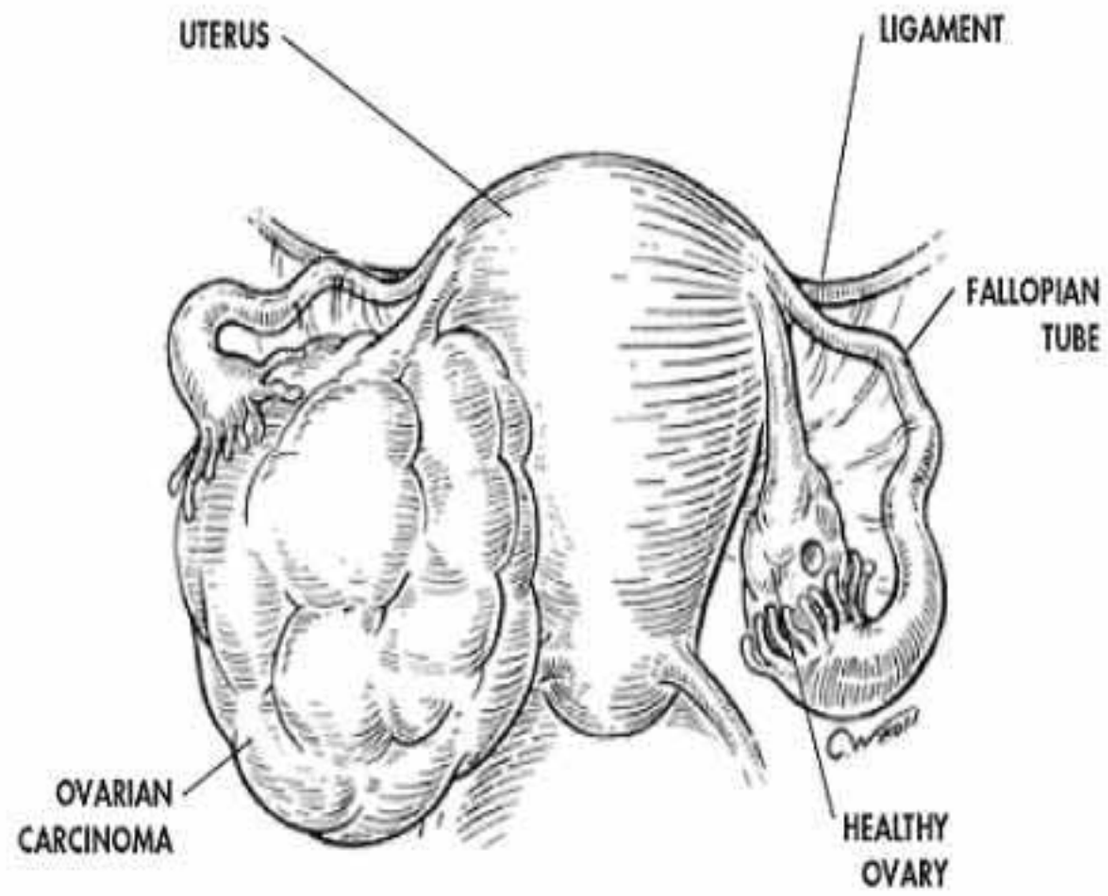
Colon Cancer and Polyp

Cancer chemotherapy

Timing doses to coincide with vulnerable S and G2 phases of dividing cancer cells

Colon cancer - 40% higher dose, 3-fold increase in >50% tumour shrinkage
(Levi et al 2001)

Improved effectiveness for treating ovarian cancer
(Hrushesky 1985)



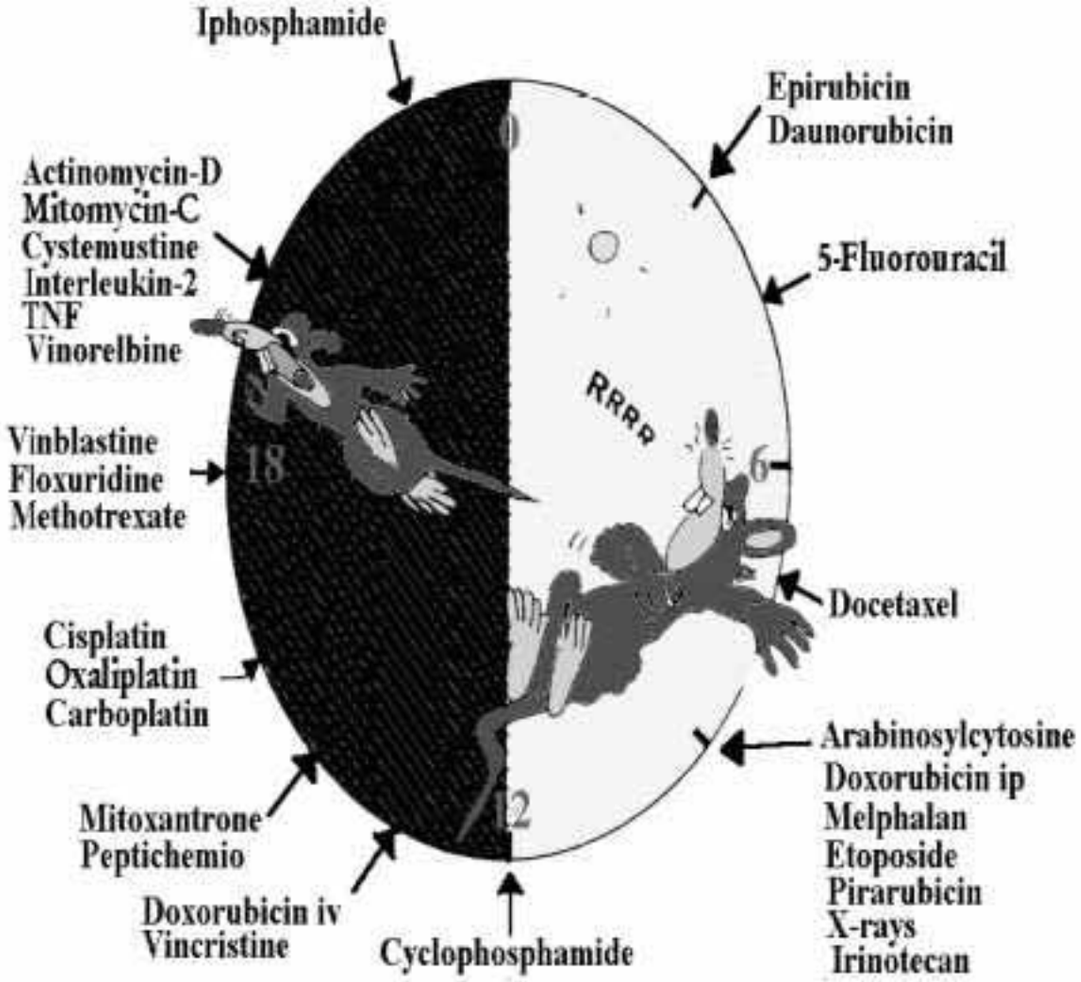
Cancer chemotherapy

Cancers with seasonal patterns
- cervical, breast and testicular

Cancer chemotherapy

Cancers with seasonal patterns
- cervical, breast and testicular

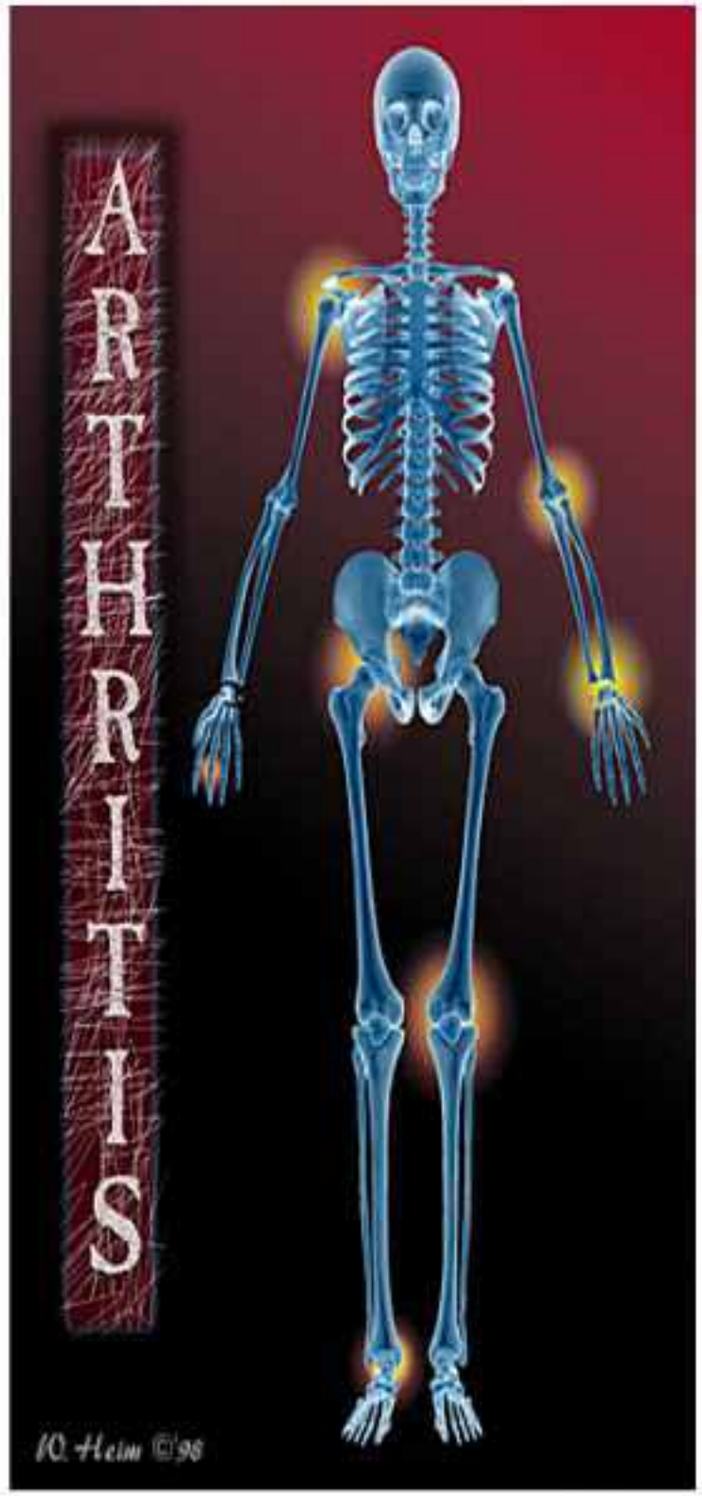
Optimal periods for screening and treatment regimes ?



Other possibilities

Rheumatoid arthritis
(peaks around 6-8am)

Osteoarthritis
(peaks around 4-6pm)



Time perception

Time and the birds and the bees

The birds and the bees are champion time users rather than sex symbols

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Bees for breakfast (August Forel 1910)

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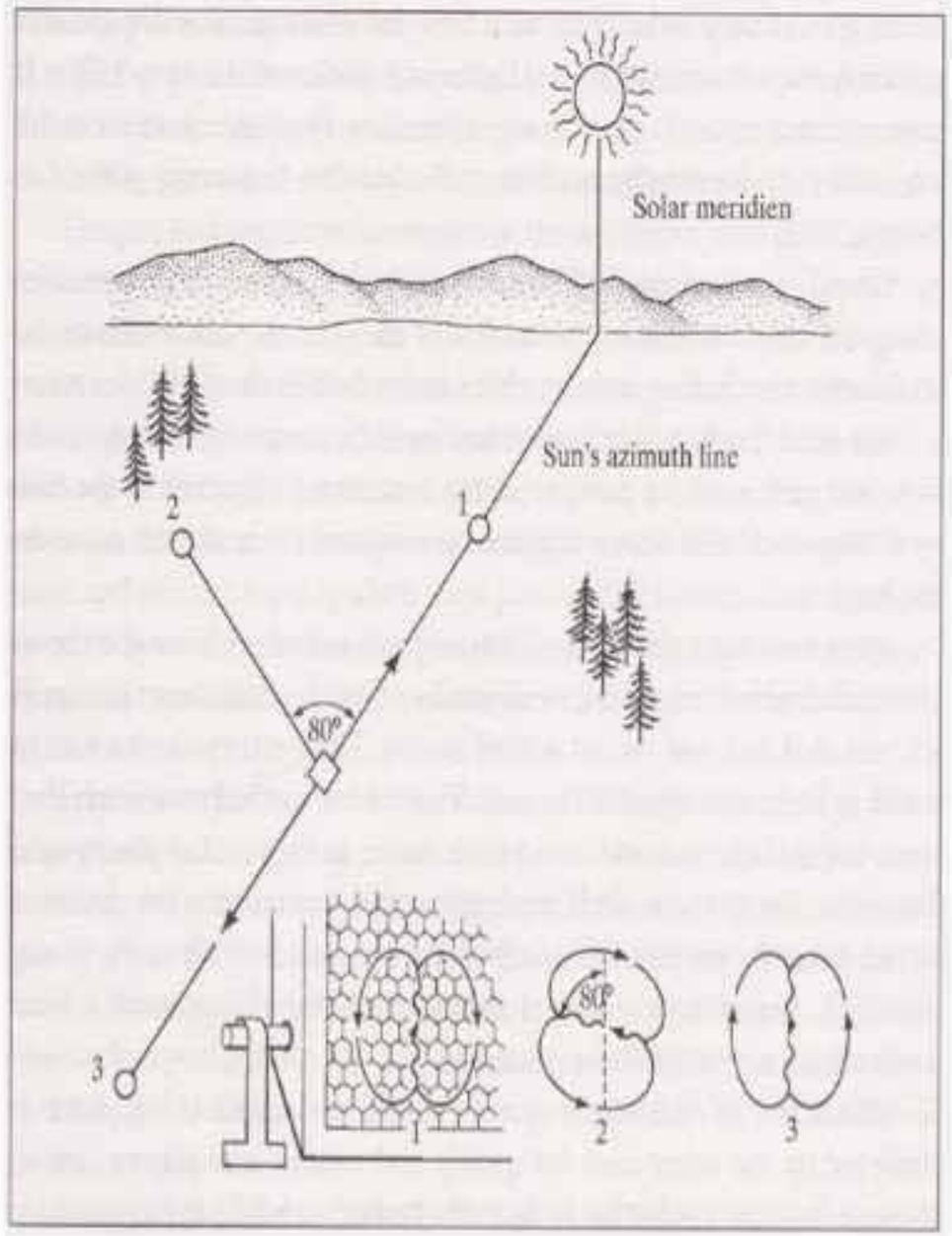
Compute time by movements of the sun (15°/hour)



Time and the birds and the bees

The birds and the bees are champion time users rather than sex symbols

Bees for breakfast (August Forel 1910)

Dancing bees (von Frisch 1950)

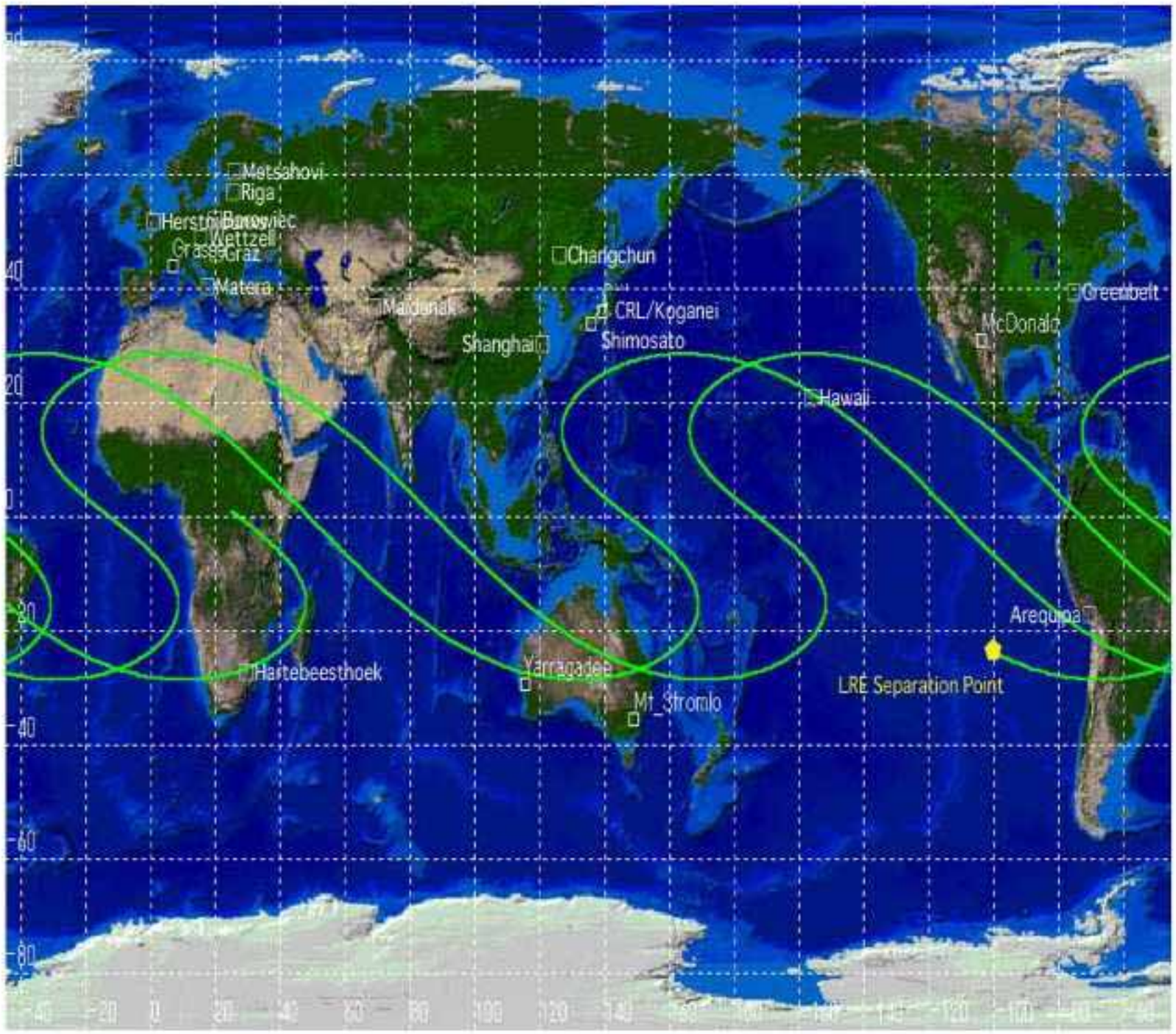
Compute time by movements of the sun (15°/hour)

The problems of curfew !

Z

Time and the birds and the bees

Biological global positioning device



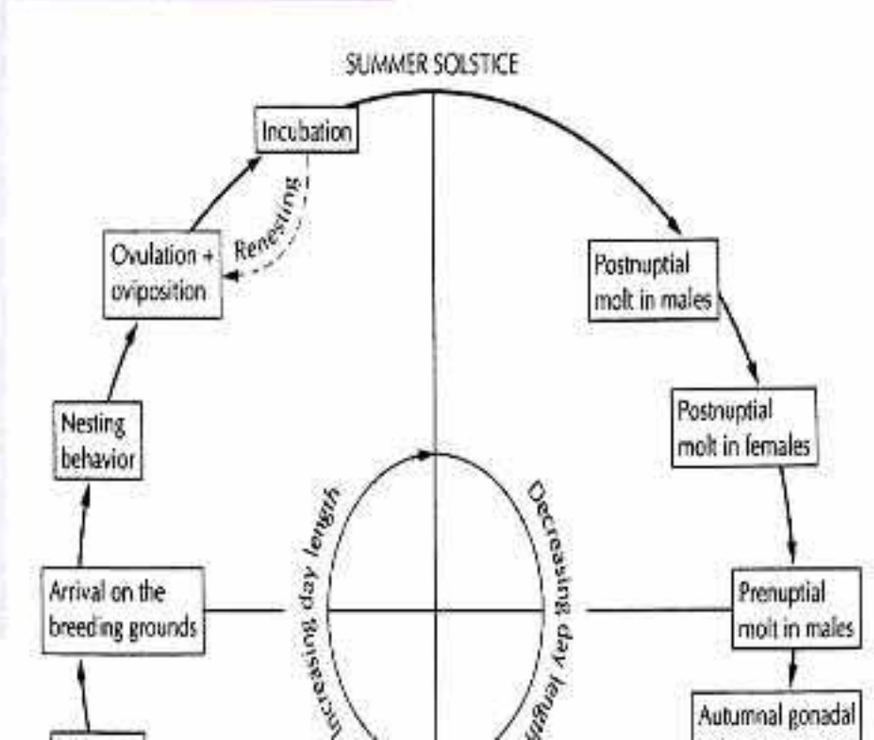
Time and the birds and the bees

Migrating birds are also champion time users

Time and the birds and the bees

Migrating birds are also champion time users

They have two clocks - a circadian and a circannual one



Time and the birds and the bees

Many other animals can be trained to perform time interval tasks

Time and the birds and the bees

Many other animals can be trained to perform time interval tasks

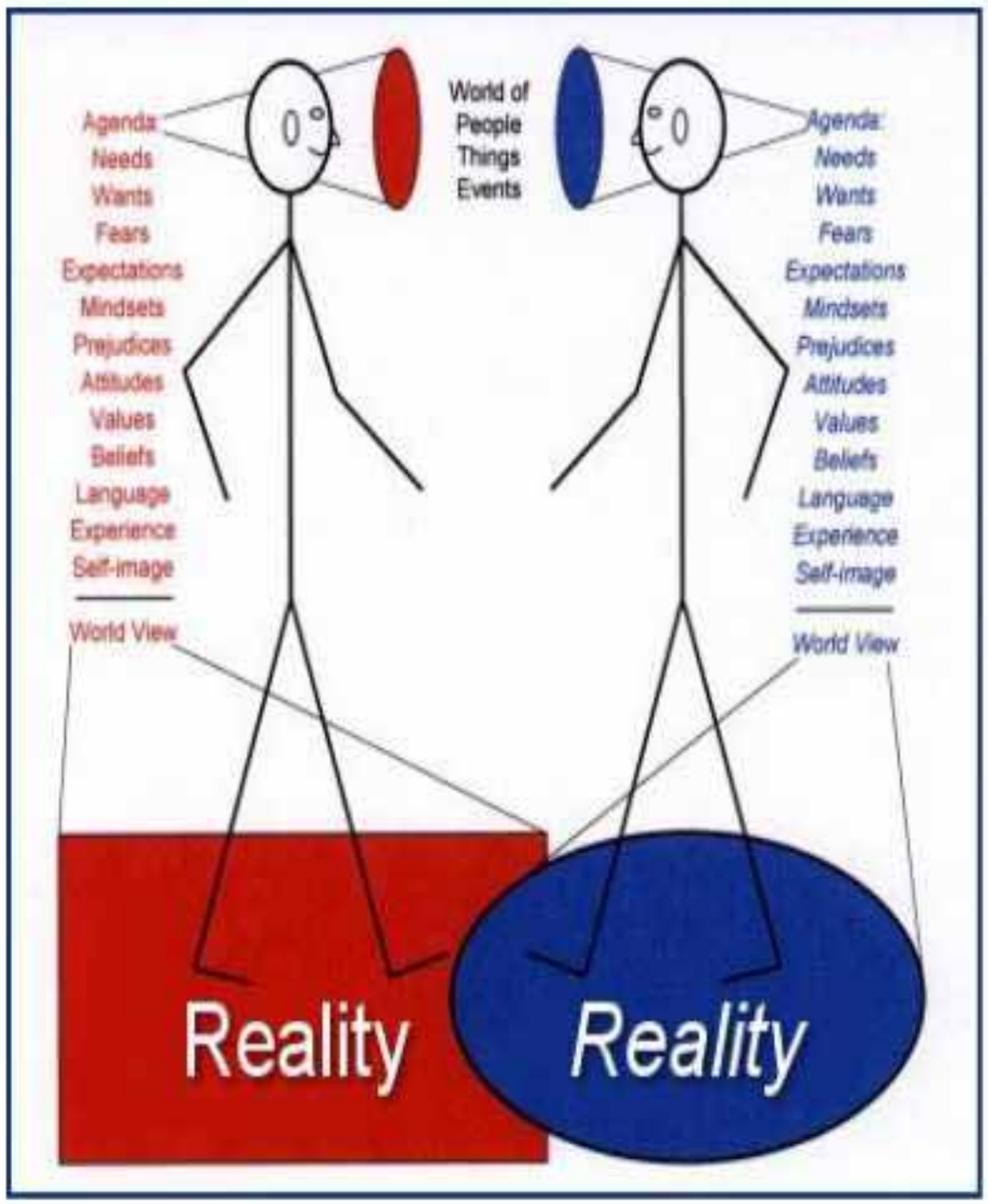
Dogs and cats waiting for owners

Time perception and consciousness

Time use to guide behaviour may not equate to having a conscious perception or a concept of it

We conceive time egocentrically

We put present, past or future events in the context of our own personal experience



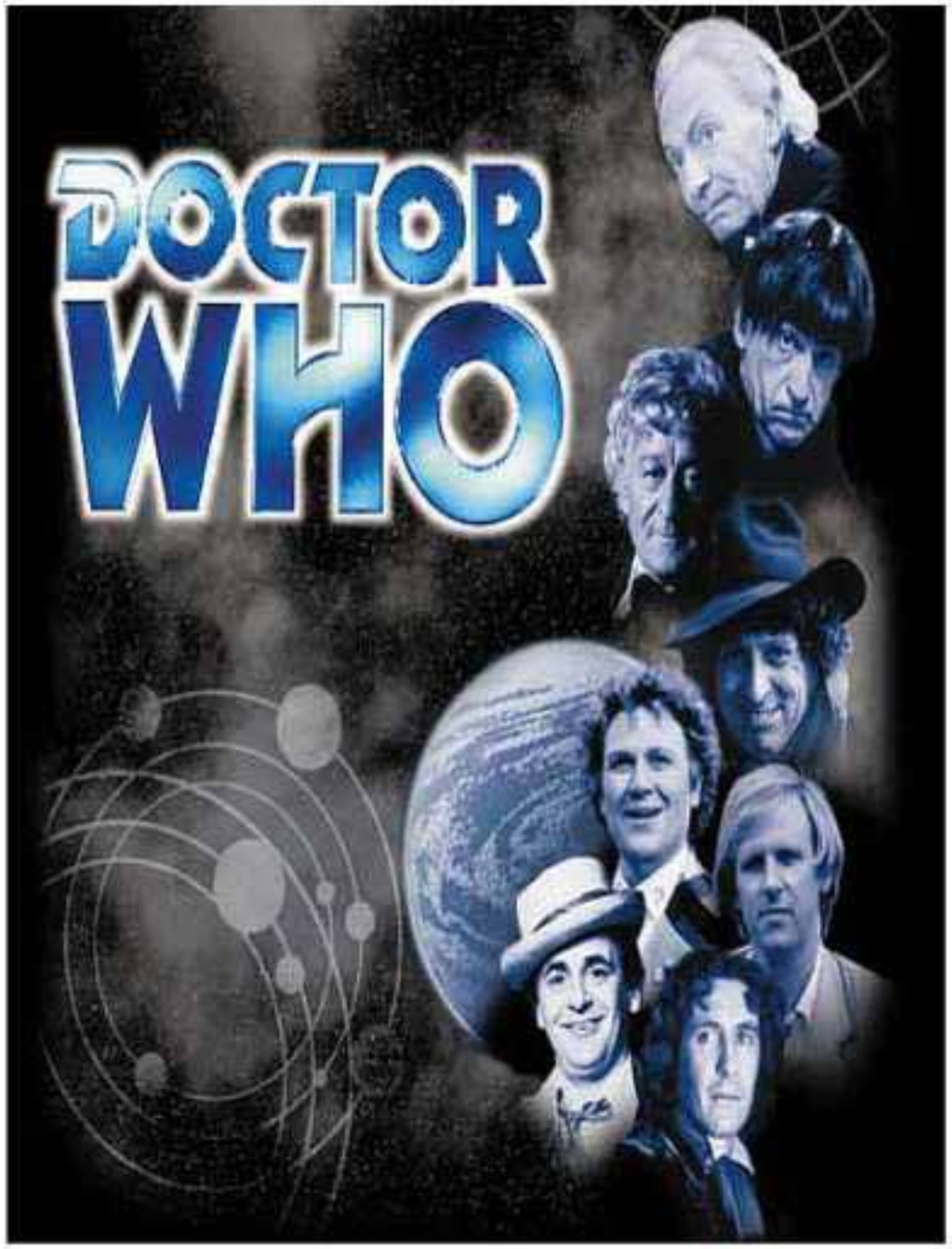
Time perception and consciousness

It requires self-consciousness to conceive of time in this way

This is in short supply in other species

Mental time travel

We are all mental time travellers



Mental time travel

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Claimed to be unique to humans

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Develops in parallel with self-awareness (2 - 4 years)

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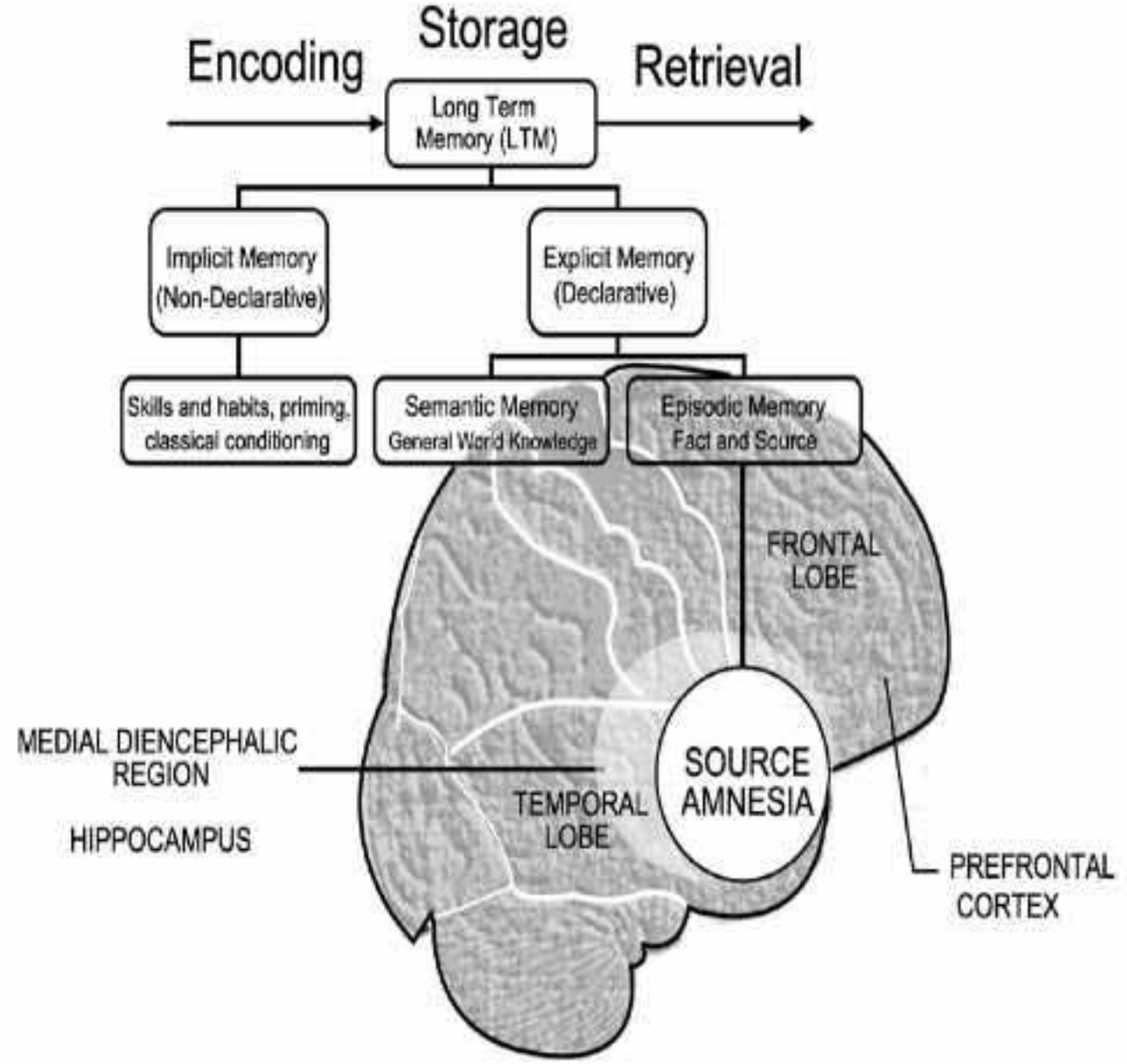
Integration of what, when and where - episodic memory



Mental time travel

Can animals really mentally revisit the past or see the possible future ?

'All forest animals, to this very day, remember exactly where they were and what they were doing when they heard that Bambi's mother had been shot'

Gary Larson

Enter the Western Scrub Jay

Mental time travel

The best things in life don't last long

Wax worms vs peanuts

4 hours

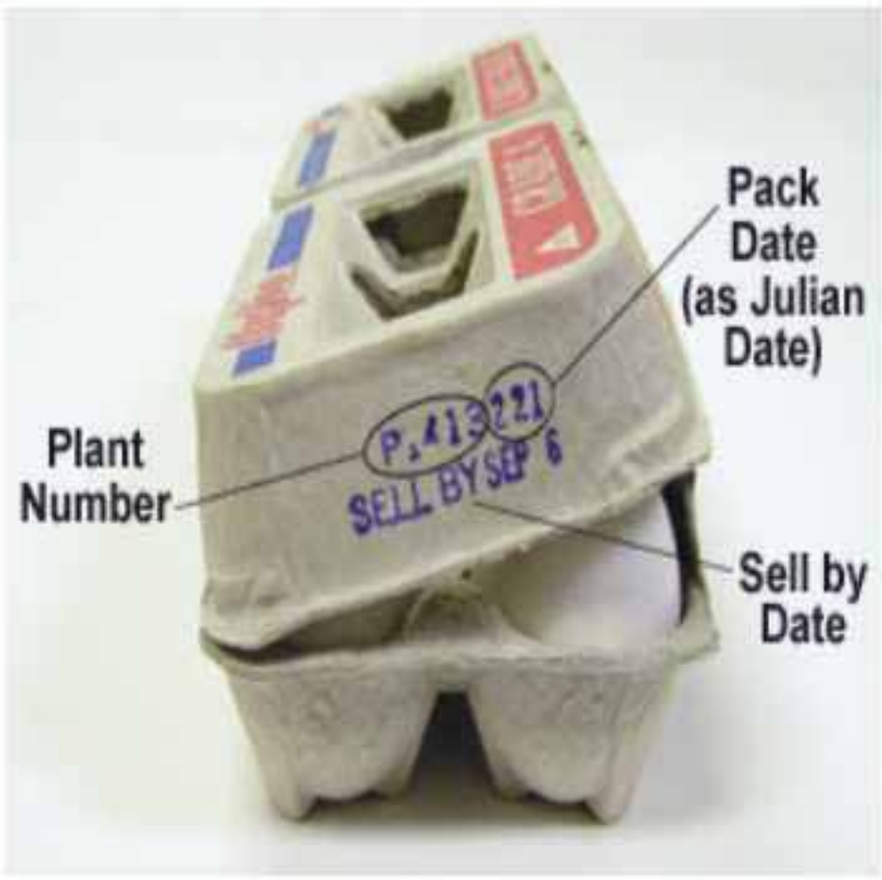
124 hours

Mental time travel

The best things in life don't last long

Wax worms vs peanuts

We tend to rely on sell-by dates



Mental time travel

The best things in life don't last long

Wax worms vs peanuts

We tend to rely on sell-by dates

Recent experiments on celebrity humans may not !

Mental time travel

Can scrub-jays see into the future ?

Caching

Observed

In private

3 hours

Recovery

In private

In private

Mental time travel

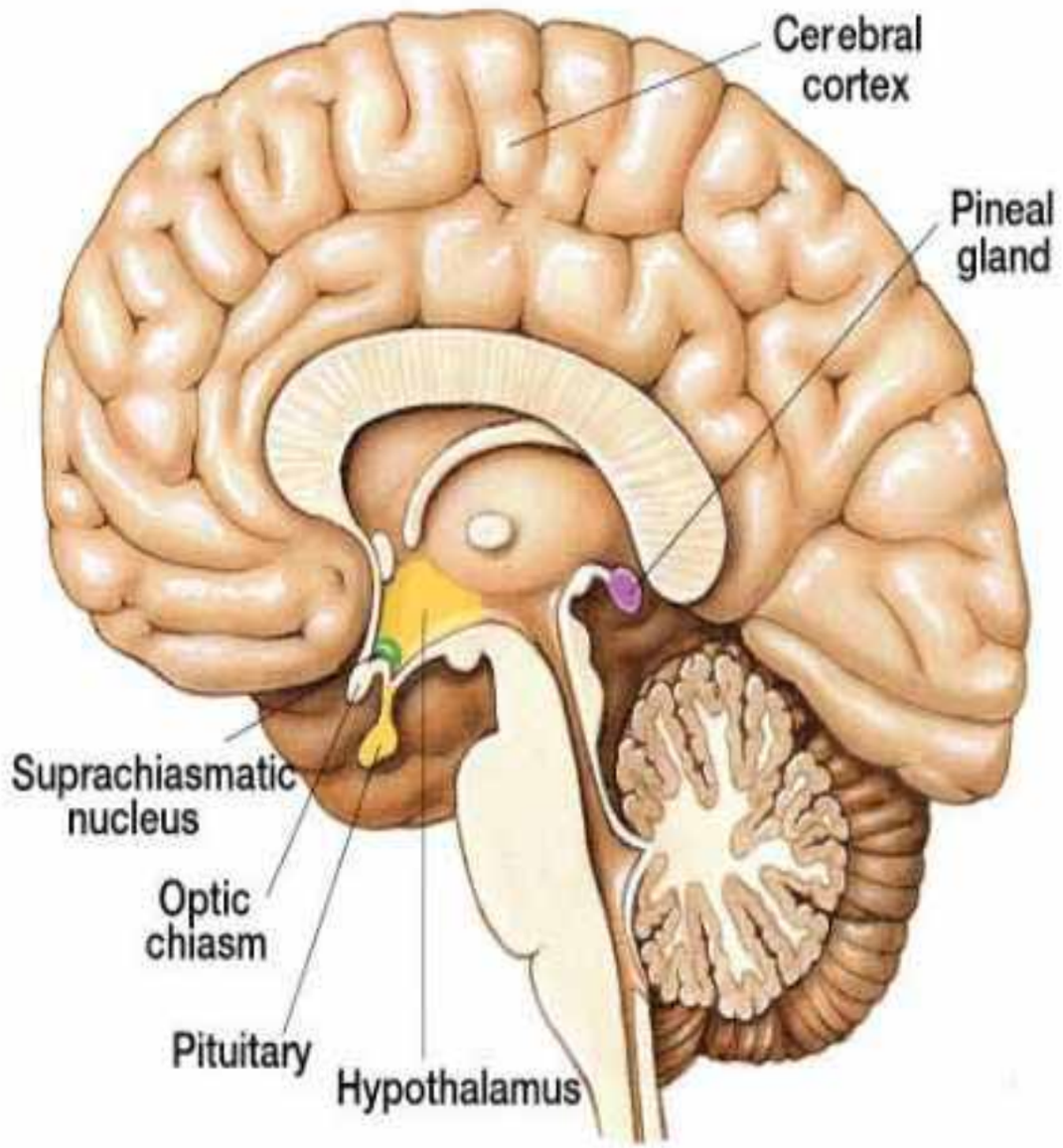
Can scrub-jays see into the future ?

Still may not need to do mental time travel to use time cues

Language apes may hold the key

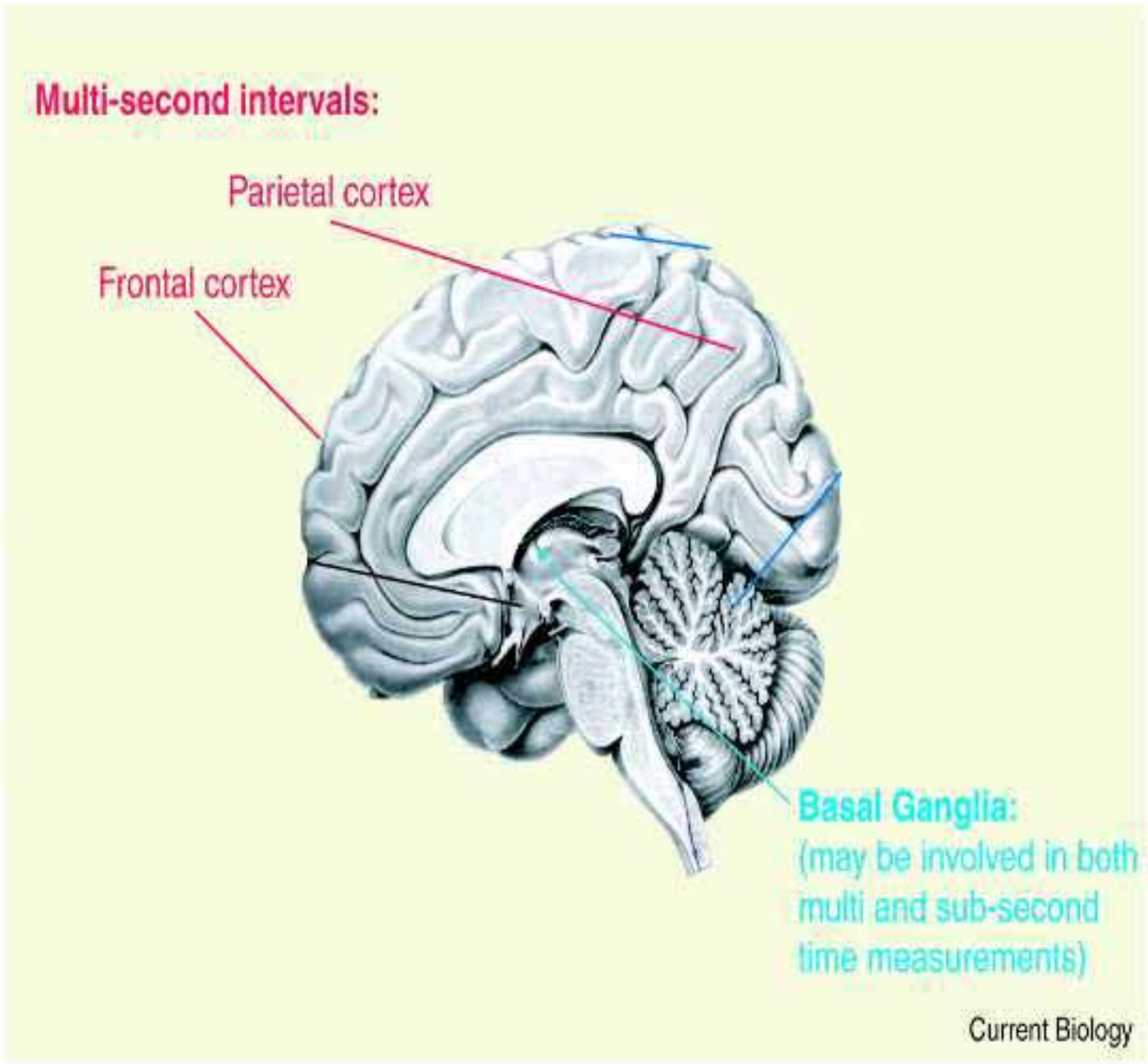
Time perception and the brain

The suprachiasmatic nucleus may not be important



Time perception and the brain

Timing involving durations of many seconds or longer tend to involve the frontal and parietal cortex



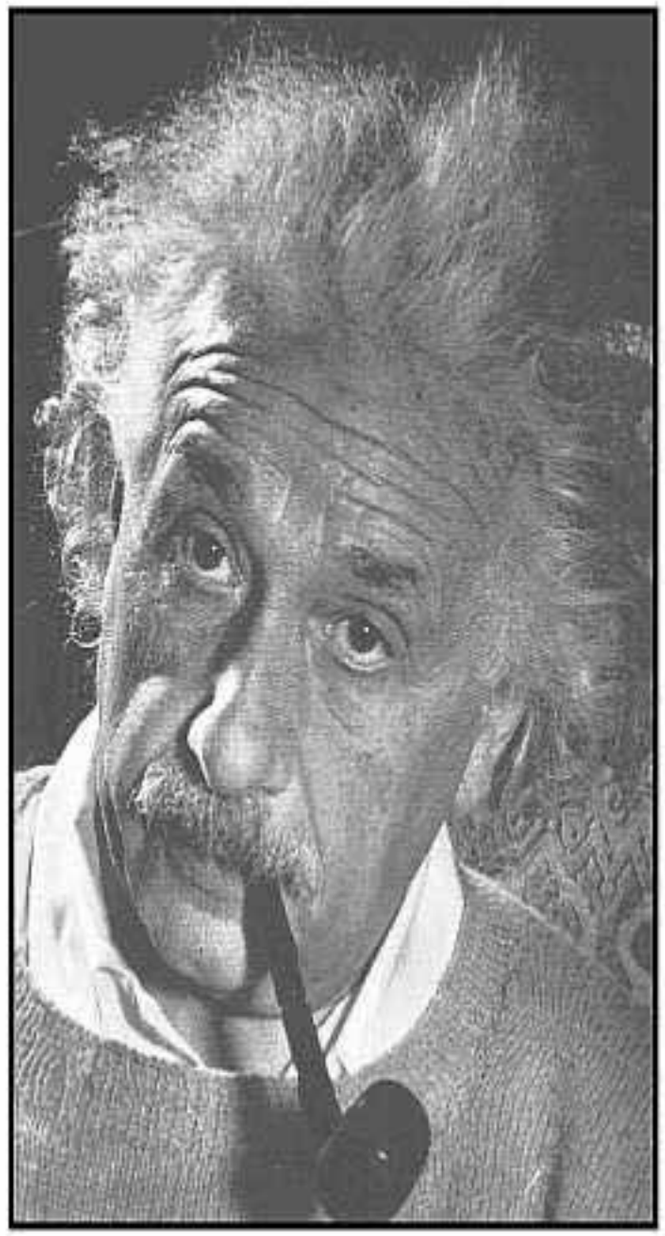
The case of KC

Tulving et al (1988)

Distortions in time perception

Time perception is highly subjective and relative to your situation

'When you are courting a nice girl an hour seems like a second. When you sit on a red-hot cinder a second seems like an hour. That's relativity'
(Albert Einstein)



Distortions in time perception

Time really is experienced faster when you're having fun

Distortions in time perception

Time really is experienced faster when you're having fun

Time really is slowed down when you are bored and depressed

Distortions in time perception

Time really is experienced faster when you're having fun

Time really is slowed down when you are bored and depressed

Time perception is distorted in Schizophrenia, Depression and ADHD

It is slowed down by high and sped up by low body temperature

Sex differences in time perception

Men underestimate short periods of time (<1 min) and overestimate long ones

Women overestimate short periods of time (<1 min) and underestimate long ones

Sex differences in time perception

'I have been on a calendar but never on time'

Marilyn Monroe

Sex differences in time perception

It may be a functional adaptation to male sex duration

Sex differences in time perception

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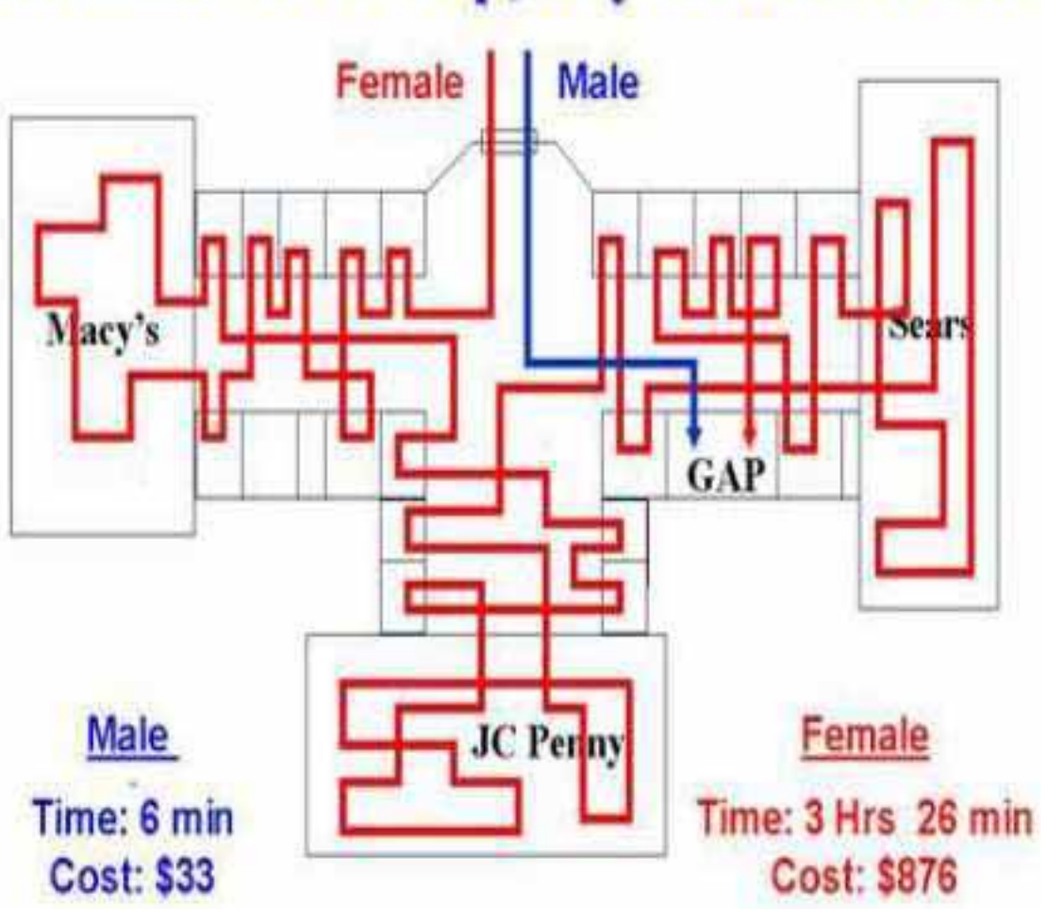
This could explain why men think they can do in a minute what women do in one hour

Sex differences in time perception

It may be a functional adaptation to male sex duration

This could explain why men think they can do in a minute what women do in one hour

Or why men think women are later than they really are



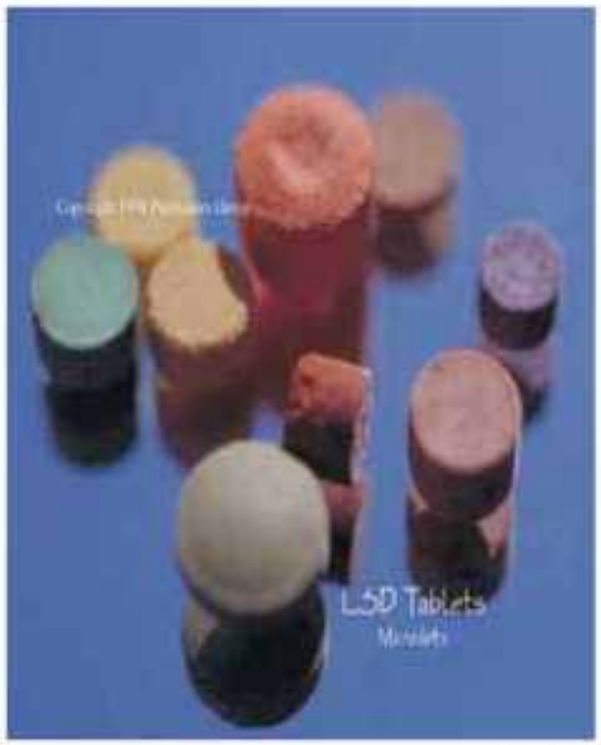
Sex differences in time perception

If women think that men take too little time over sex.....

Men know that they take even less time than women think !

Drugs and time perception

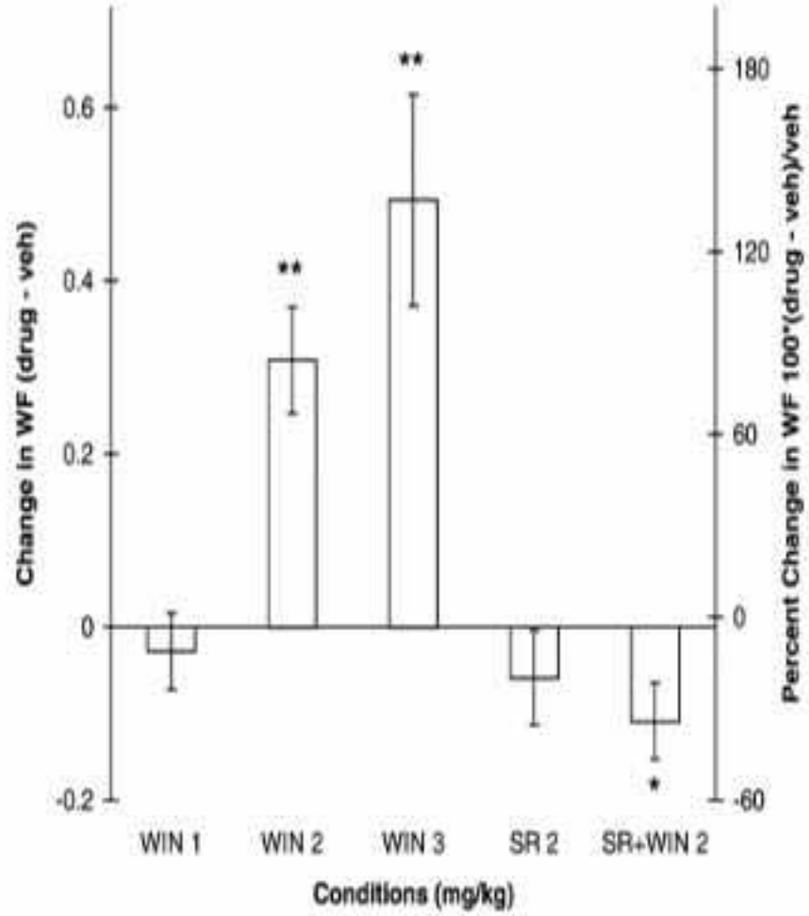
Cannabis, opium and LSD slow down time perception of time



Drugs and time perception

Cannabis, opium and LSD slow down time perception of time

Even rats on cannabis can no longer discriminate short from long intervals



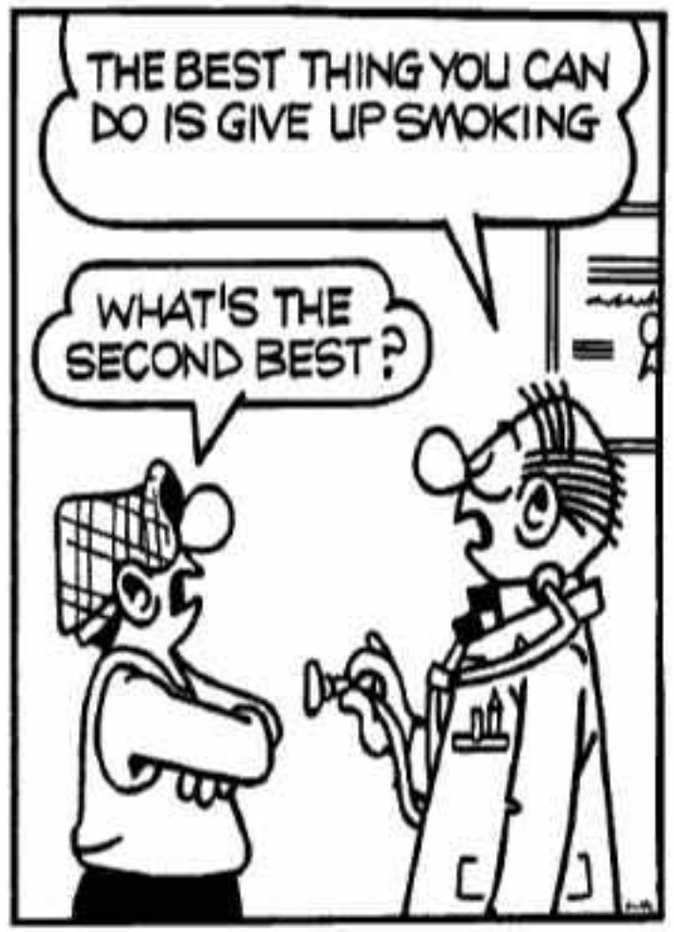
Crystal *et al*
Behavioural Brain Research (2003)

Drugs and time perception

Cannabis, opium and LSD slow down time perception of time

Even rats on cannabis can no longer discriminate short from long intervals

Giving up smoking makes time drag



Time effects on memory accuracy

Time distorts accurate memory for events

Schmolk et al (2000)

Time effects on memory accuracy

Time distorts accurate memory for events

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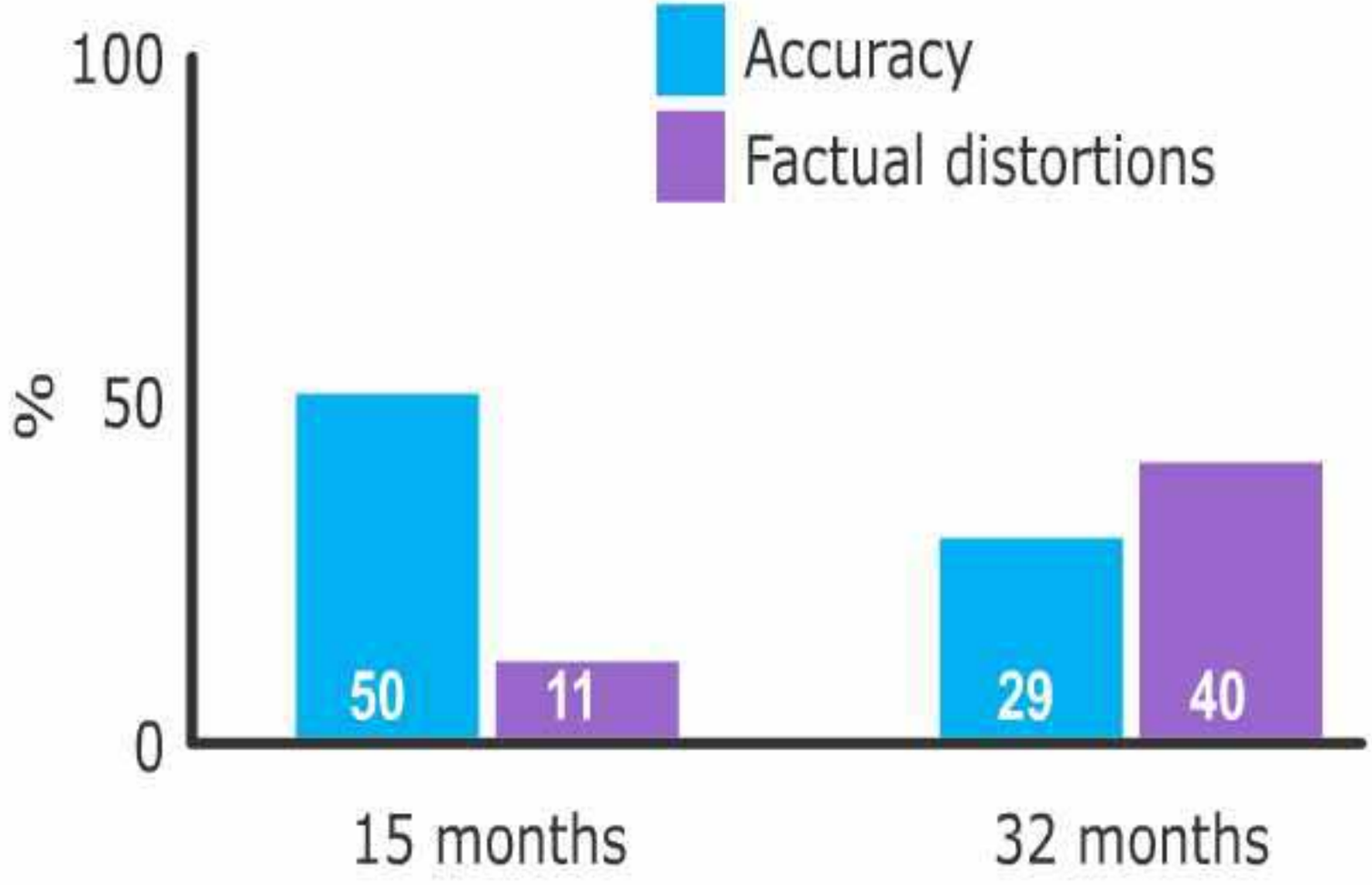


Time effects on memory accuracy

Time distorts accurate memory for events

Schmolk et al (2000)

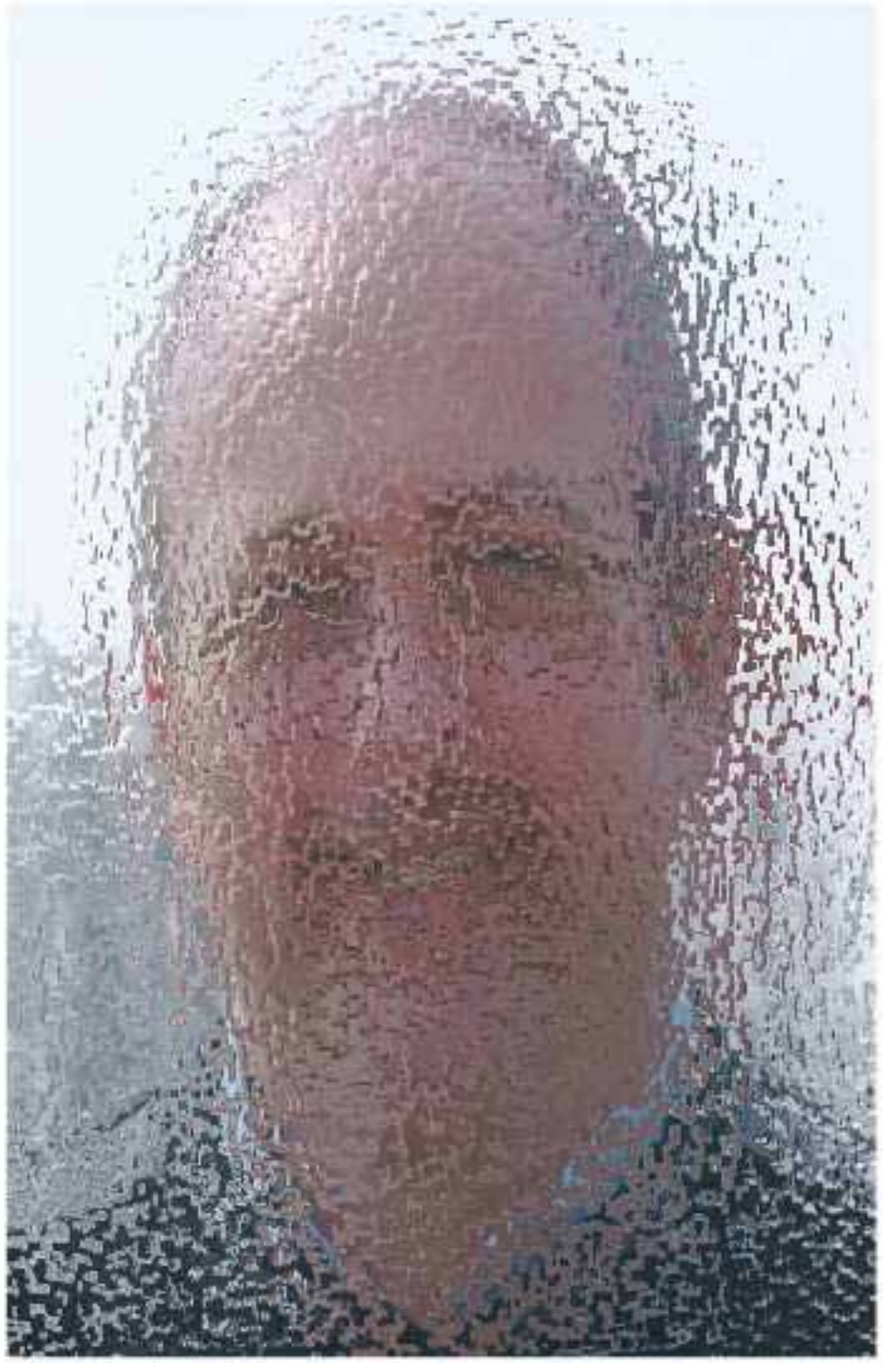
Don't rely on brains as long-term accurate repositories of events

Time effects on memory accuracy

Why does the brain distort memory for events ?

Time effects on memory accuracy

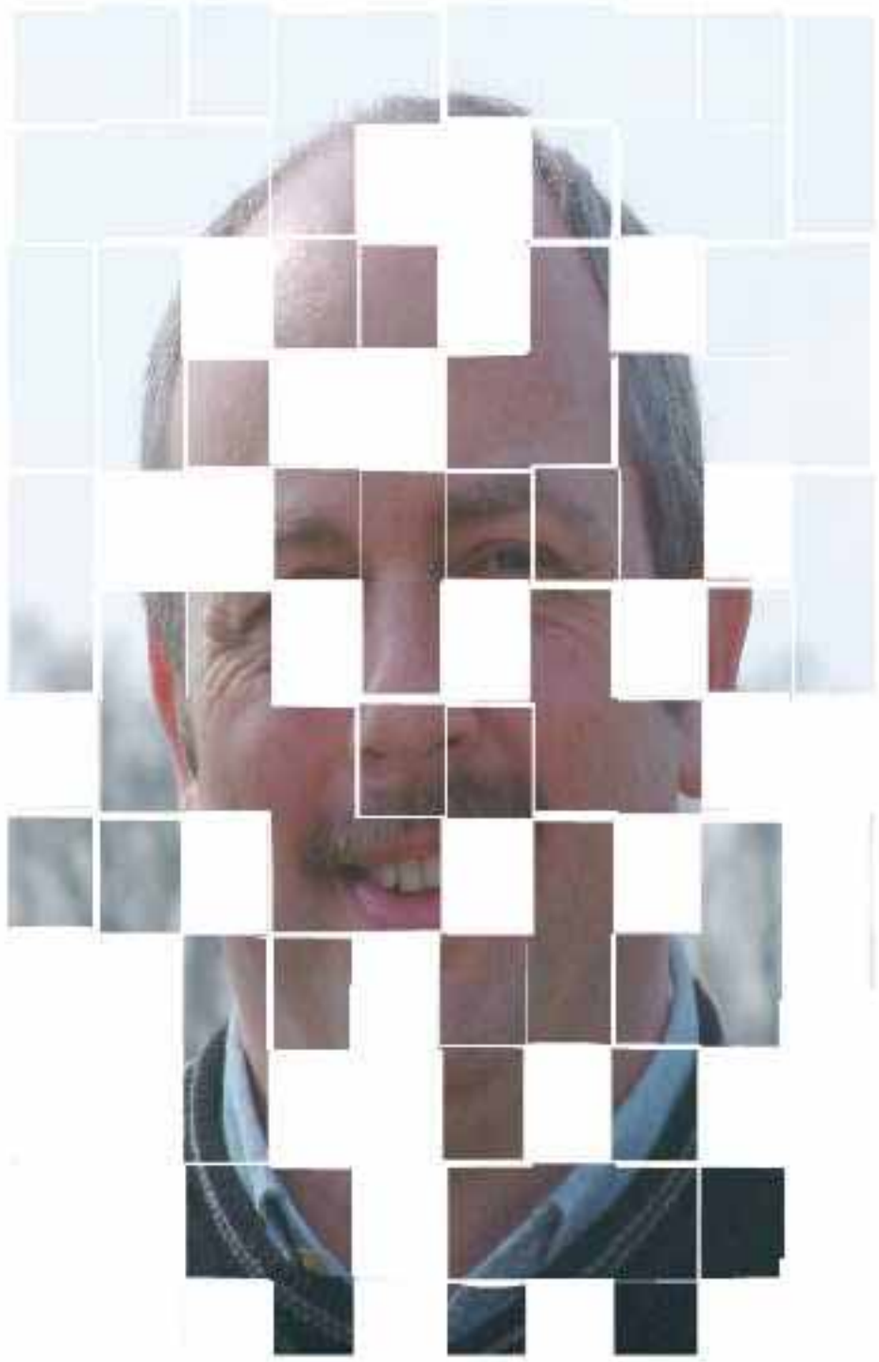
Why does the brain distort memory for events ?



Time effects on memory accuracy

Why does the brain distort memory for events ?

Active recall only brings back snippets of information

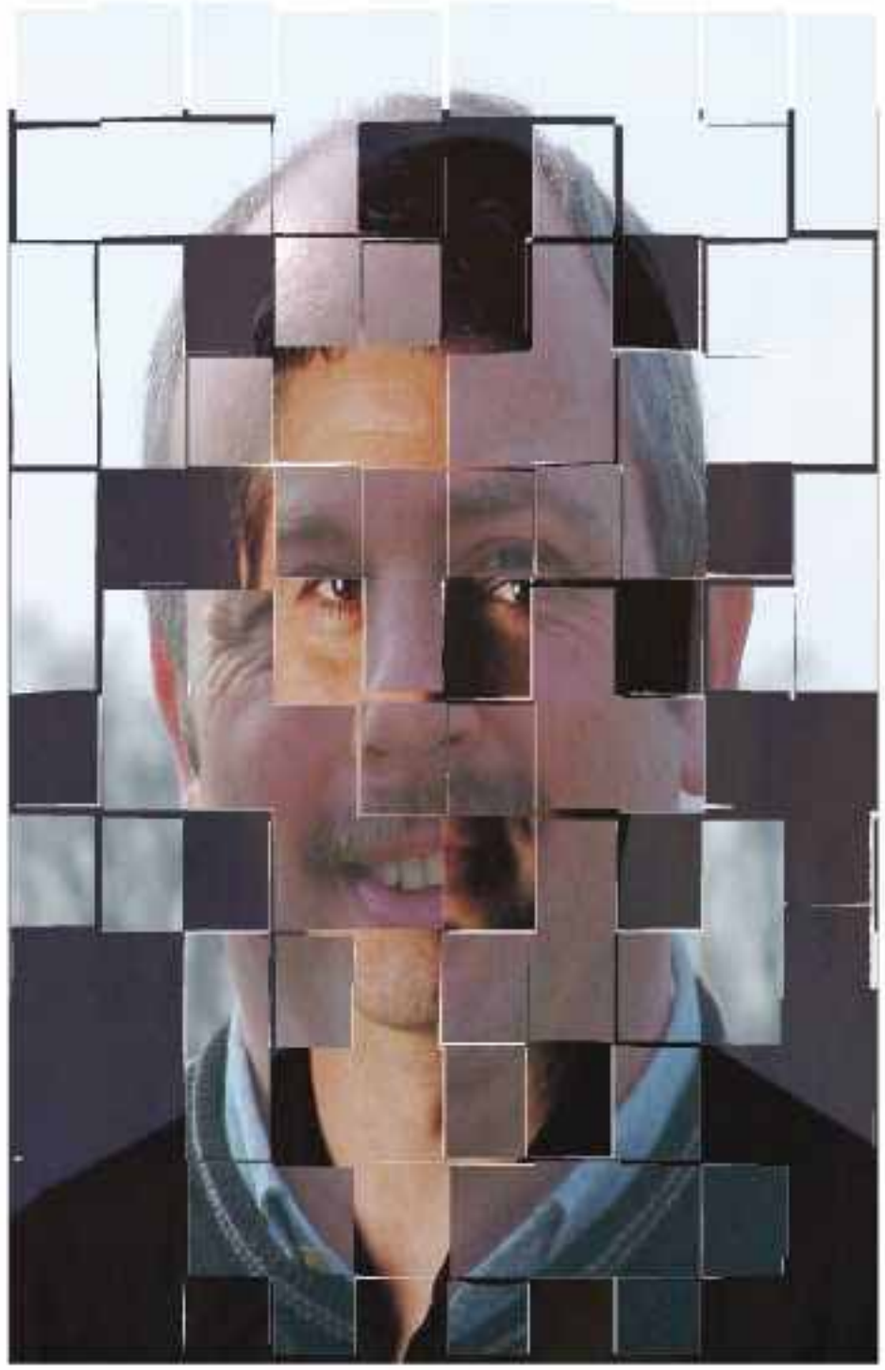


Time effects on memory accuracy

Why does the brain distort memory for events ?

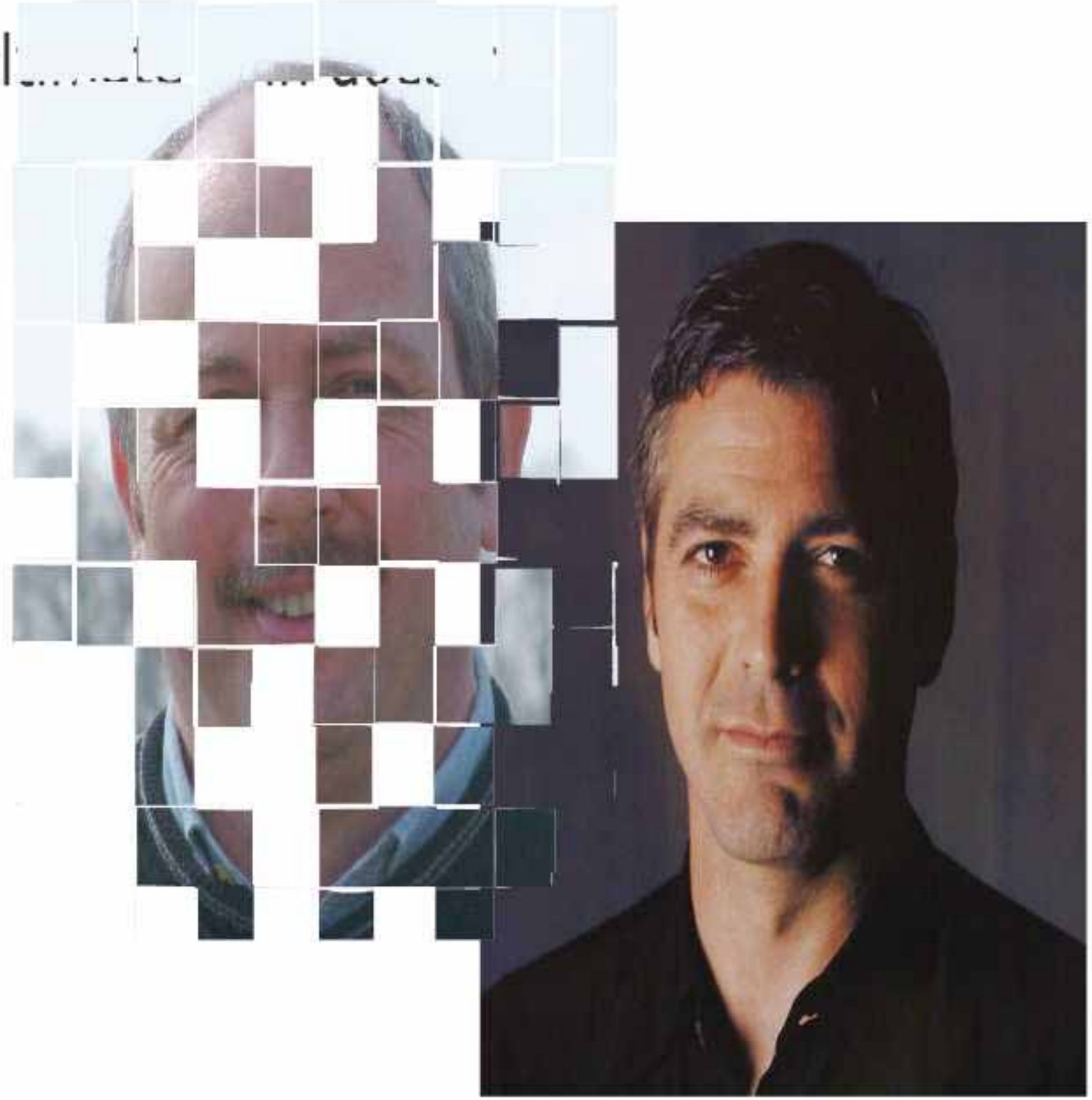
Active recall only brings back snippets of information

The brain fills in the blanks in whatever way seems suitable



Time effects on memory accuracy

Your brain is the ul...



Time effects on memory accuracy

Your brain is the ultimate spin doctor

The past is seen through rose-tinted glasses

Some general conclusions

Our rhythms are our own but are harmonised with nature

Our bodies are full of highly accurate molecular-based clocks

Frequent disruption of your body clocks is bad for health

Some general conclusions

Our rhythms are our own but are harmonised with nature

Our bodies are full of highly accurate molecular-based clocks

Frequent disruption of your body clocks is bad for health

Understanding control of body clocks may help in the fight against cancer

With medical treatments when they are given may be as important as what they are

Some general conclusions

Birds and bees know more about time than sex

Time passes more quickly when you're having fun

Men and women may not see time passing in the same way

Conscious mental time travel may be unique to humans

Time progressively distorts the brain's version of past events