Why do things sometimes change so fast?
Tipping Points in Life and Nature

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Do you want to live in interesting times?

寧為太平犬，不做亂世人

pinyin: níng wéi tàipíng quǎn, bù zuò luànshì rén

"It's better to be a dog in a peaceful time than be a man in a chaotic period"

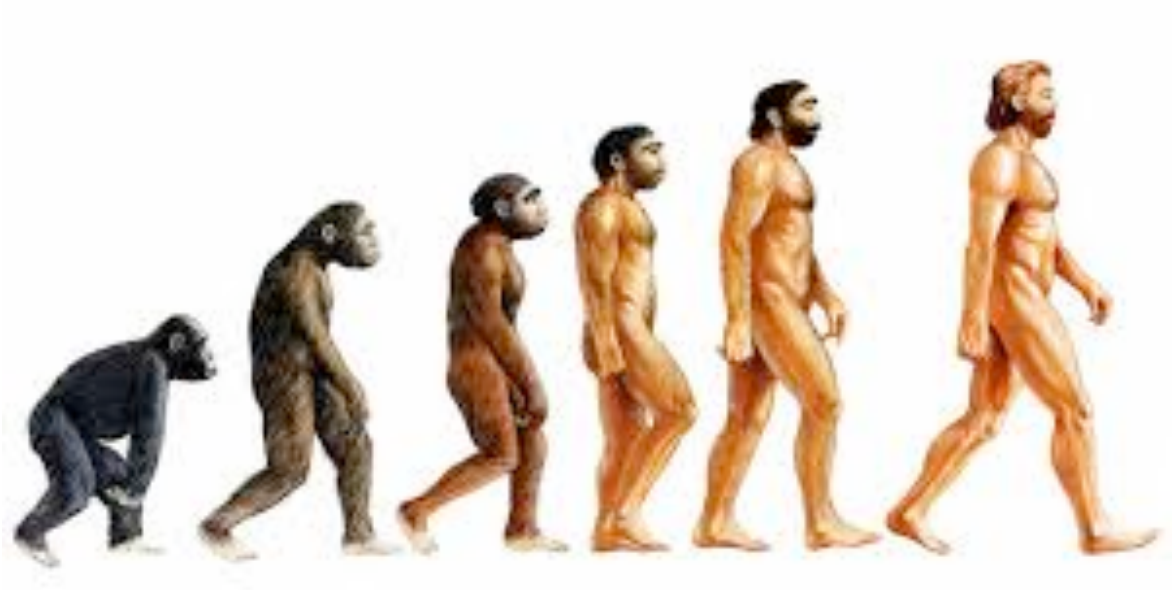
Sometimes things change slowly

Boring but safe

Sometimes they change quickly

Interesting but dangerous

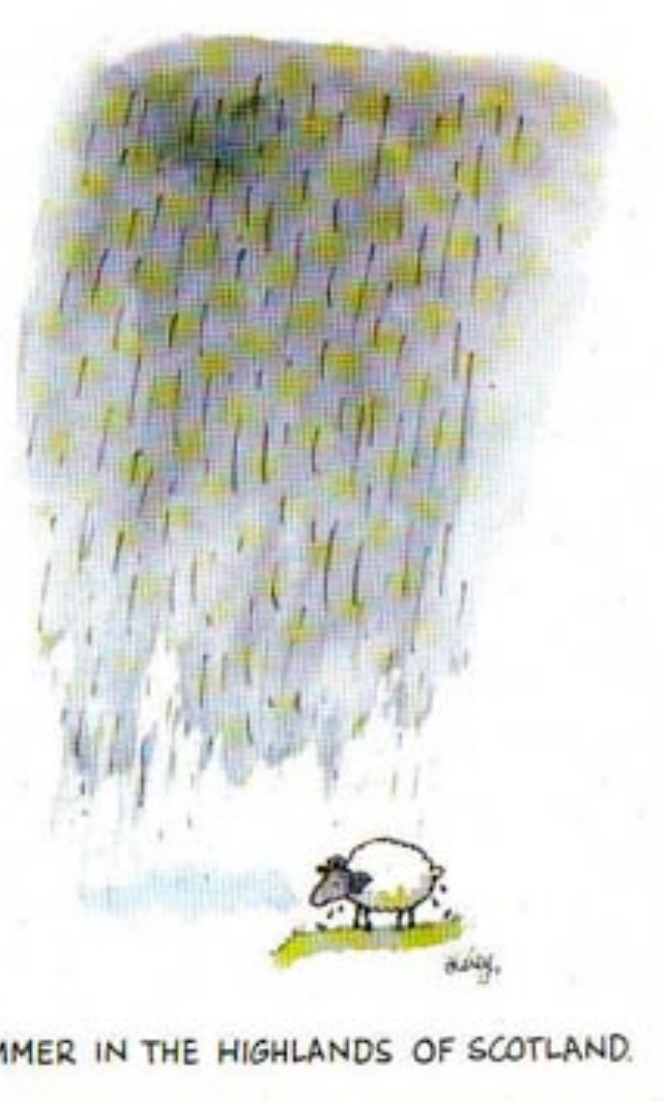
Darwin's theory of evolution seemed to imply that things happen gradually



Lots of other things are like this ..

Even the weather 70% of the time!

WINTER IN THE HIGHLANDS OF SCOTLAND.



SUMMER IN THE HIGHLANDS OF SCOTLAND.

But sometimes things (including the weather) can change very quickly ..

Why do we see sometimes see sudden changes?

Tipping points:

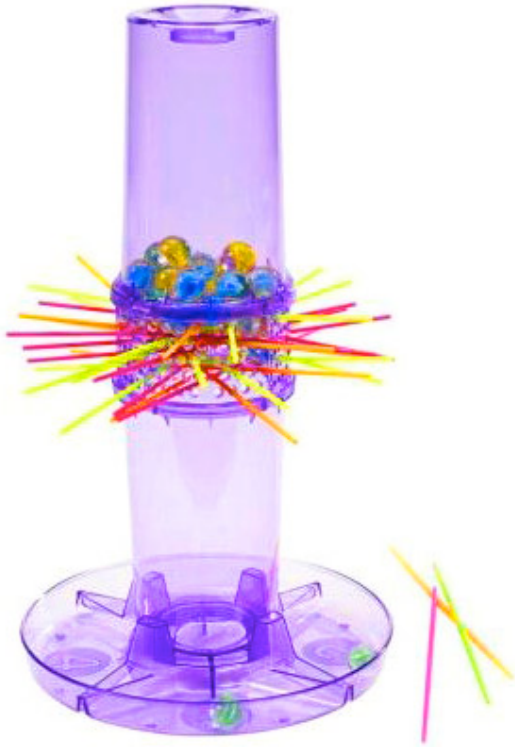
where change happens

A System is in a state of balance

Small change to it leads to an irreversible large change

Some examples of tripping points in life and nature

Kerplunk



Trigger: The final straw

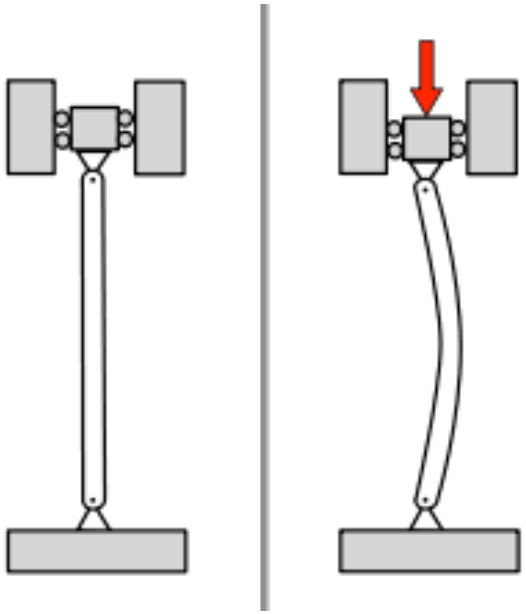
Avalanches and Sandpiles

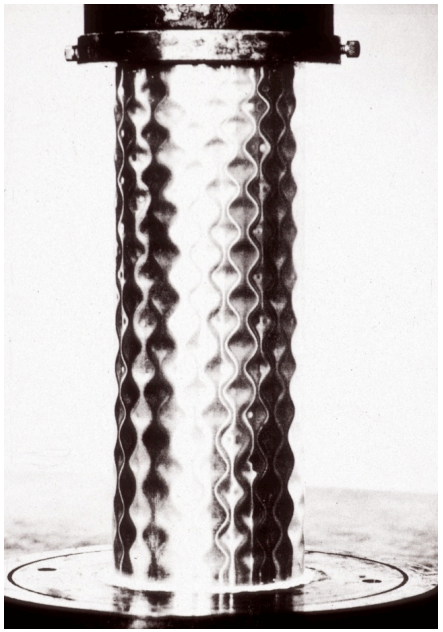
Trigger … small change in temperature or pressure

Buckling eg. Coke can

Tipping point:

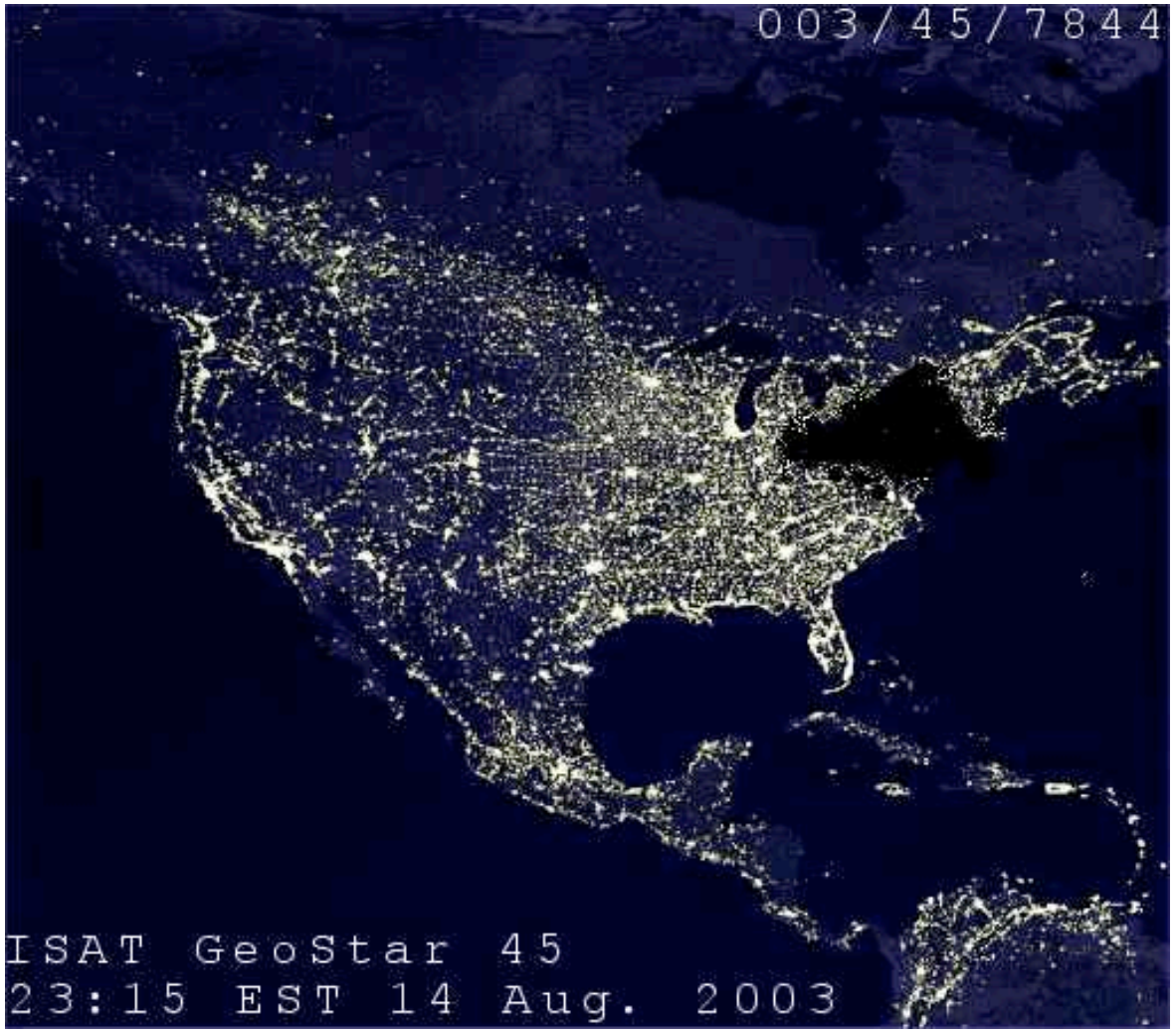
Just too much force, heat or an imperfection





Rock folding

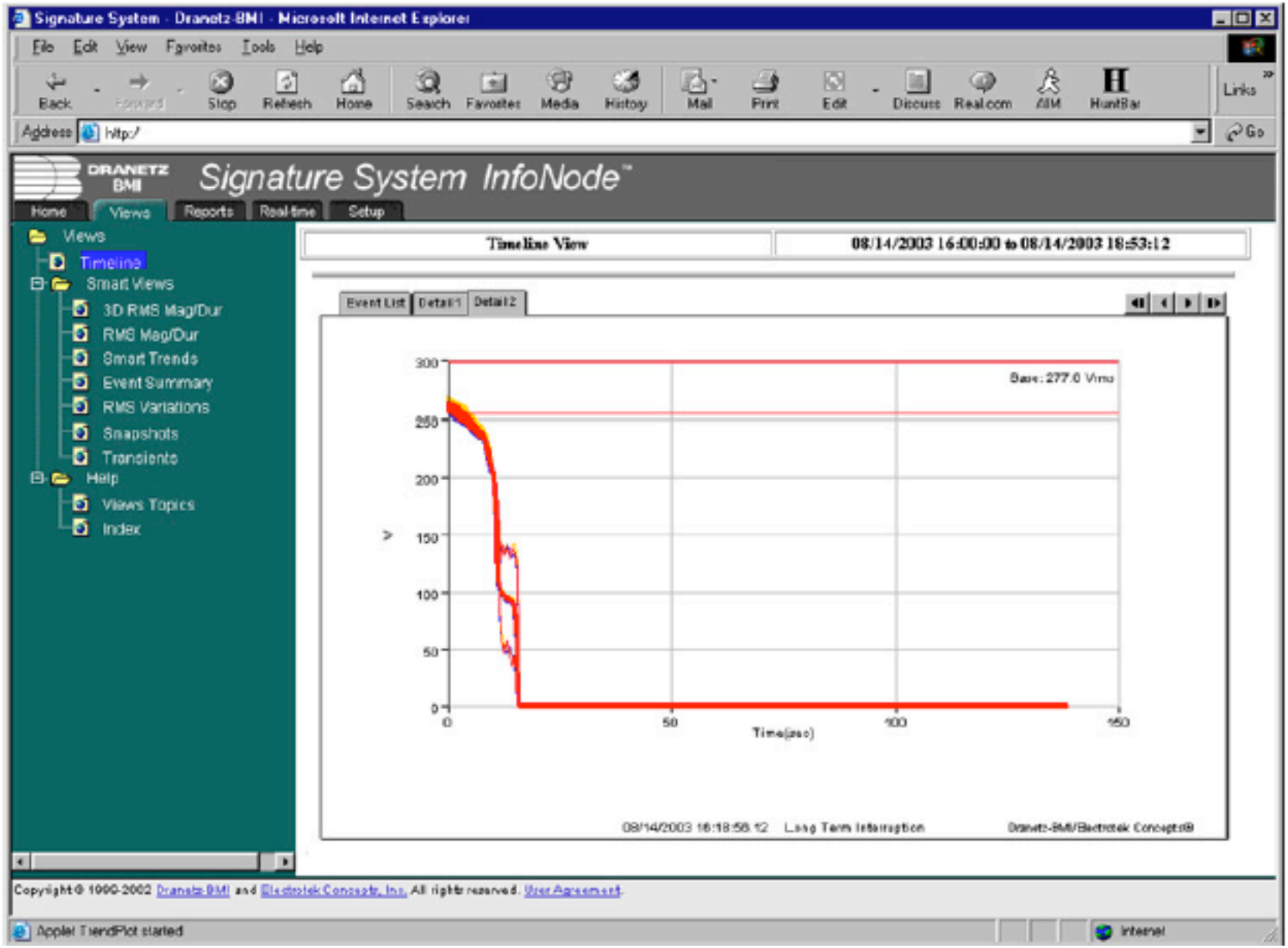
New York Blackout 2003



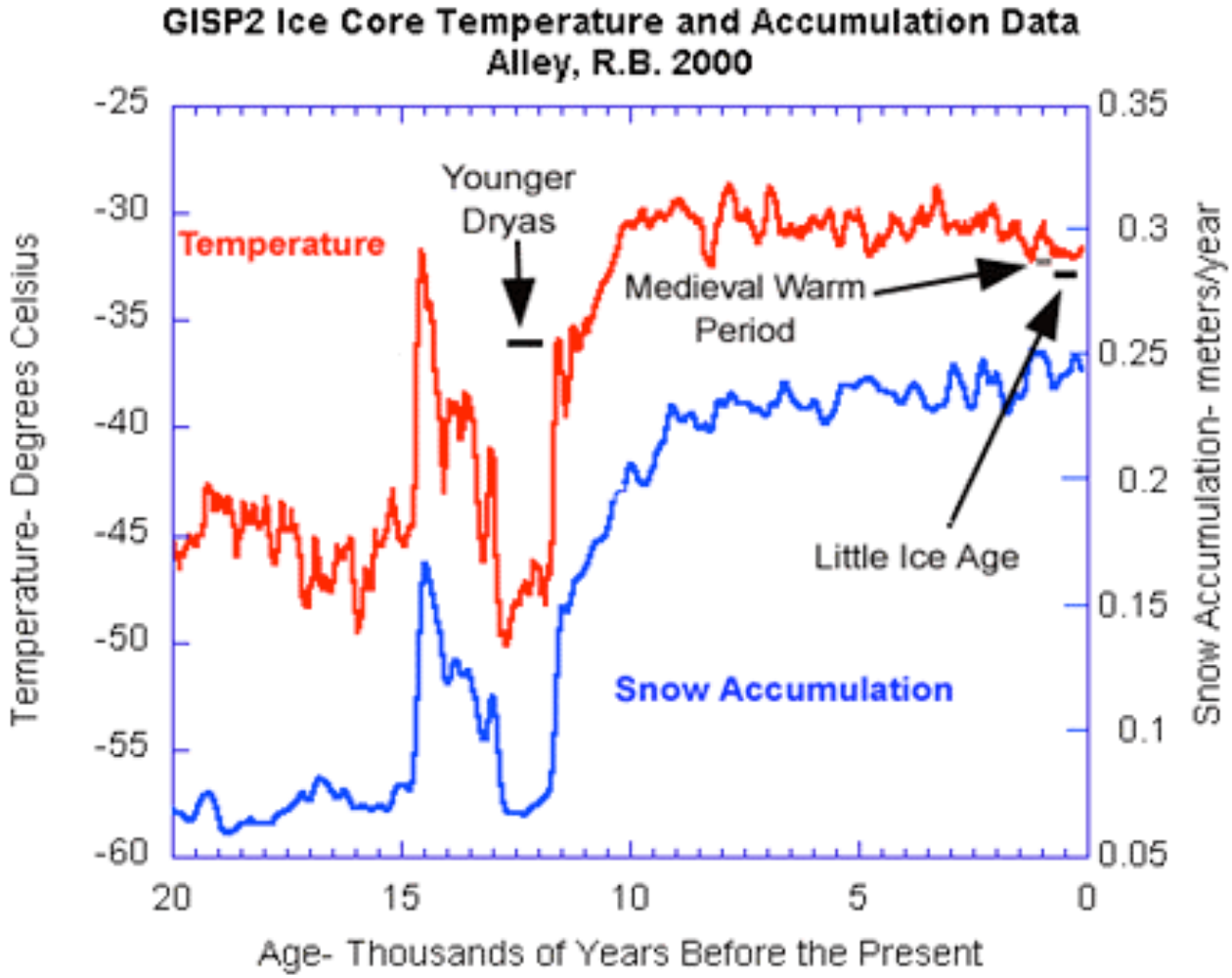
Tipping point: series of local line failures .. Global cascade

Voltage Collapse at a Site on Staten Island

PSE

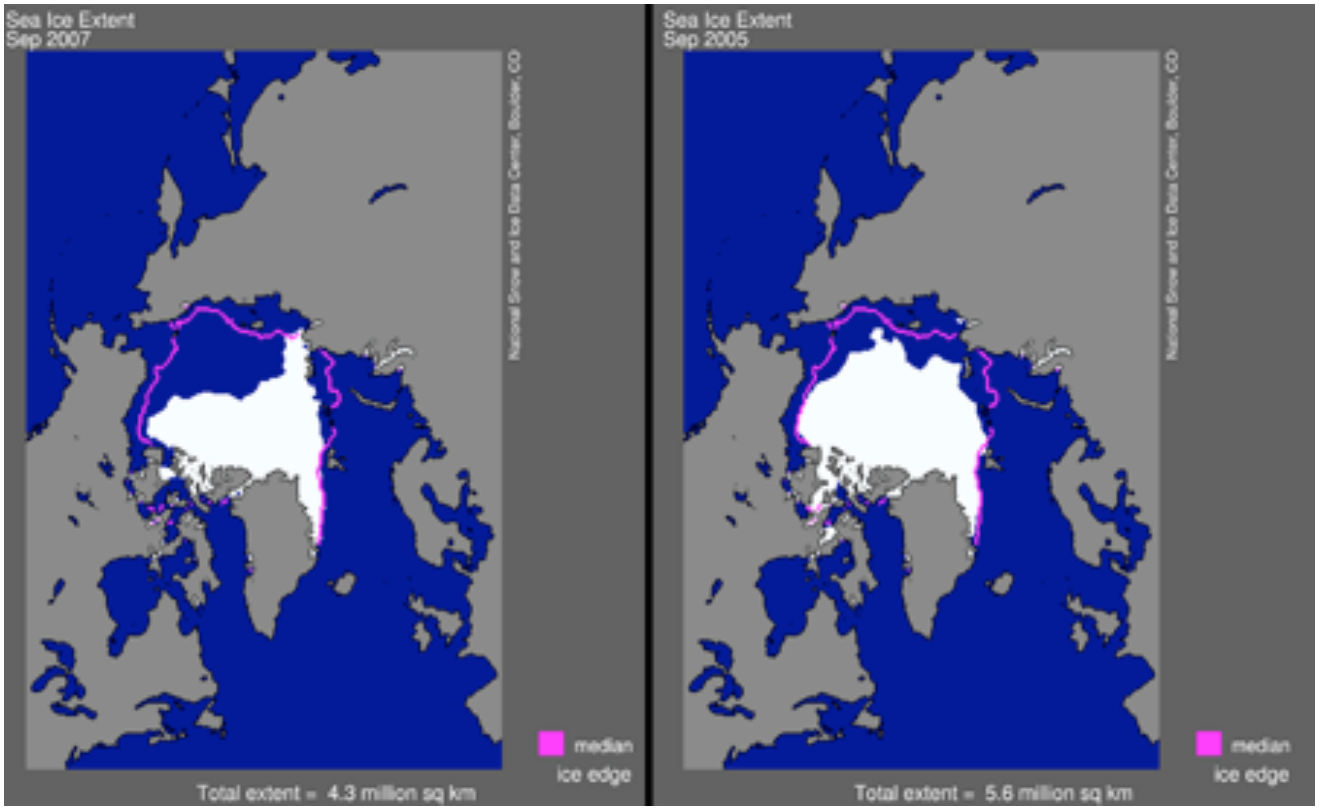


Paleoclimate: Younger Dryas Ice Age



Tipping point: ?? Shut down in the Atlantic conveyor

Current climate: The Melting Arctic ?



2007 **2005**

Every year we lose Arctic ice the size of Scotland!

Tipping point: Too much man made CO2??

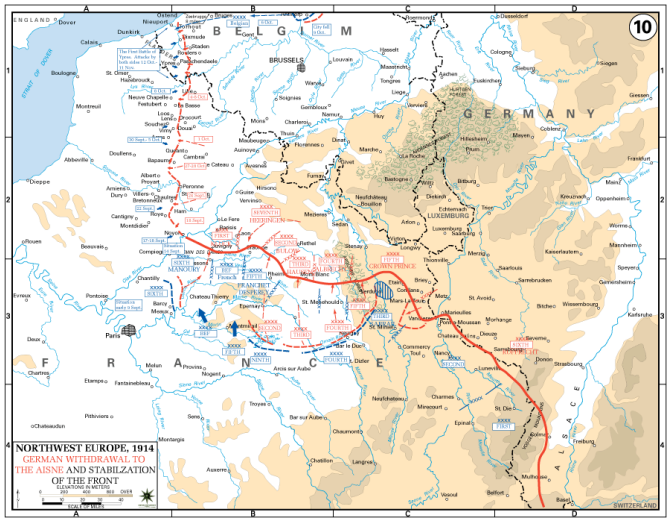
World War One

Failure of deterrence

Tipping point:

Shooting of Franz Ferdinand at Sarajevo
by Gavrilo Princep

German Railway Timetables



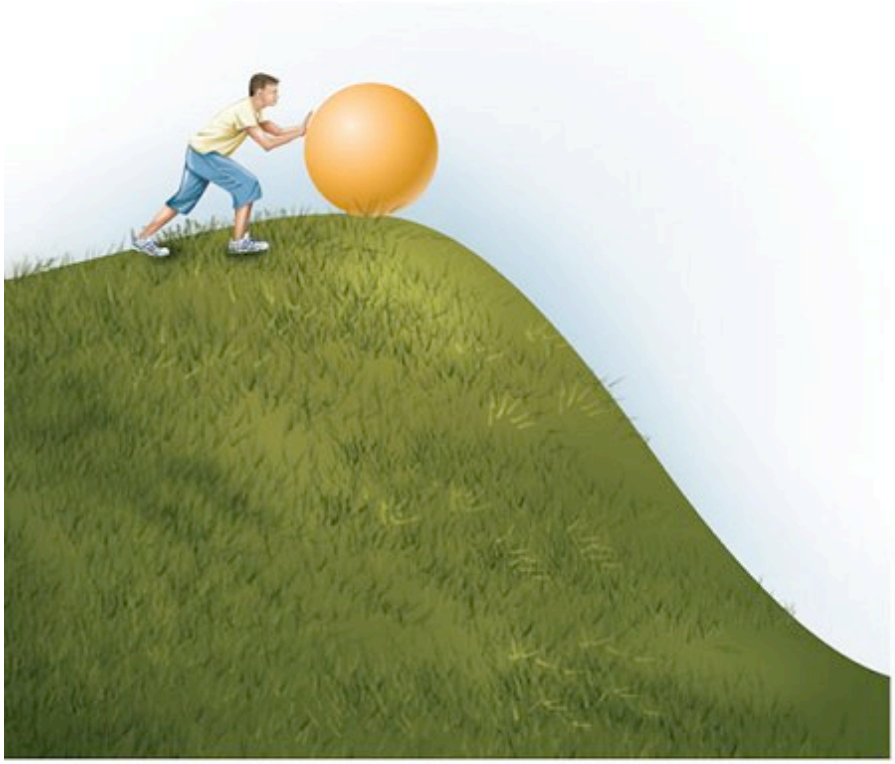
A theory for tipping points

Apple cart has two stable states separated by an unstable state

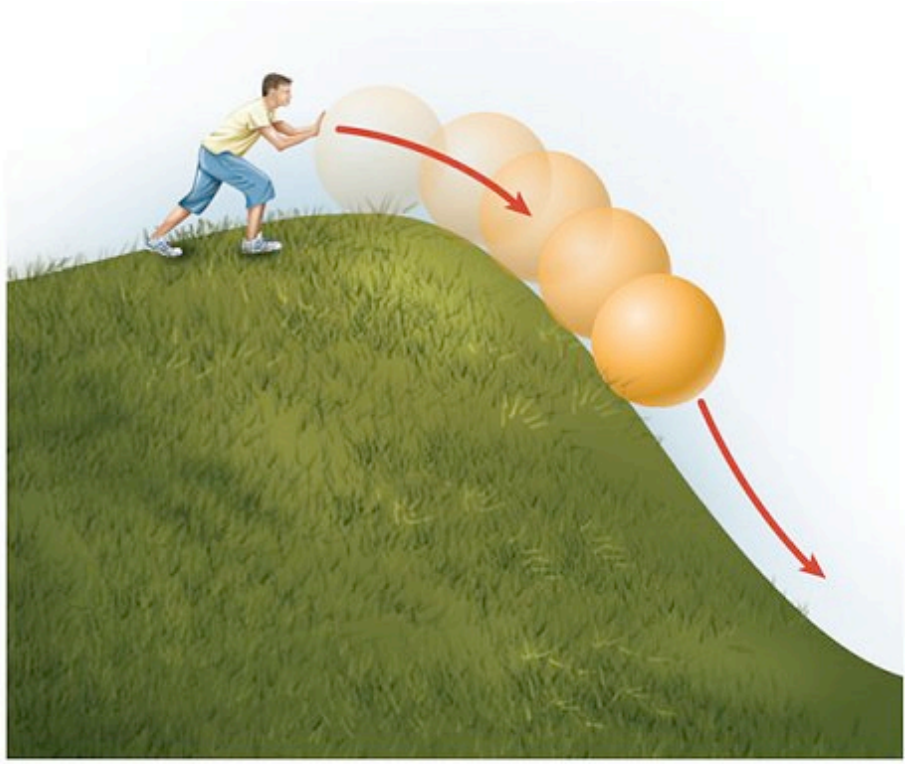
A ball in a hole is in a stable state

Small change leads to small effect

A ball on the top of a hill is unstable



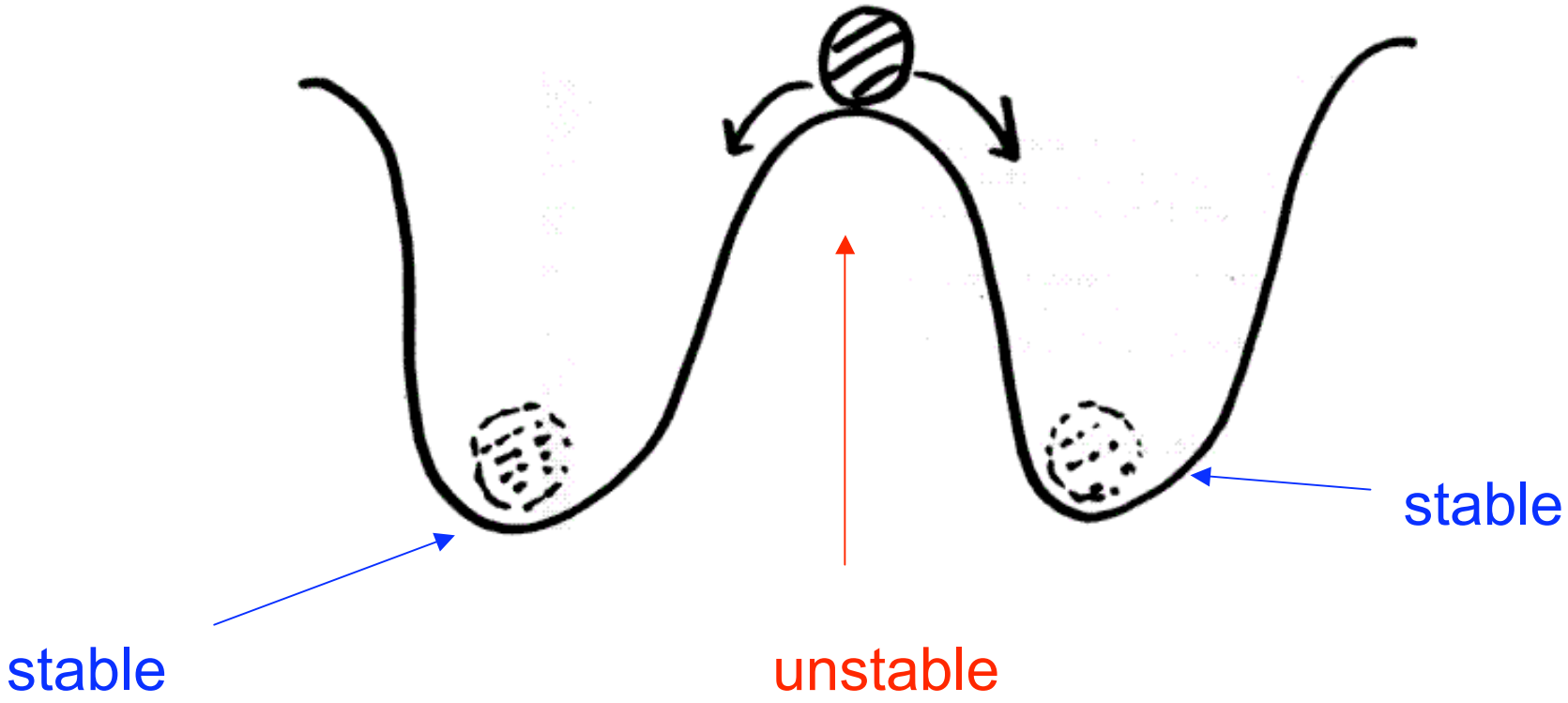
a) Potential energy



(b) Kinetic energy

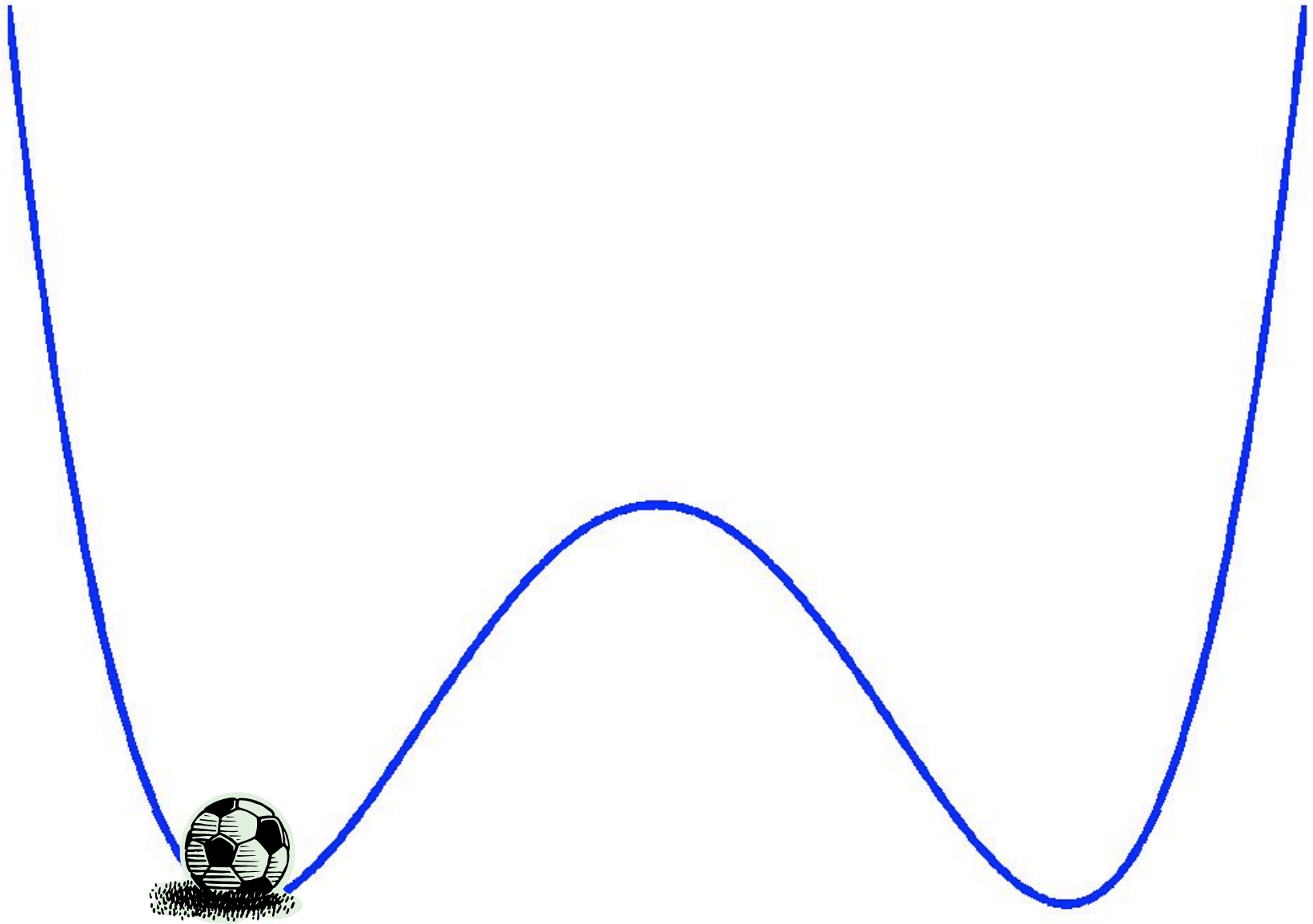
Small change leads to large effect

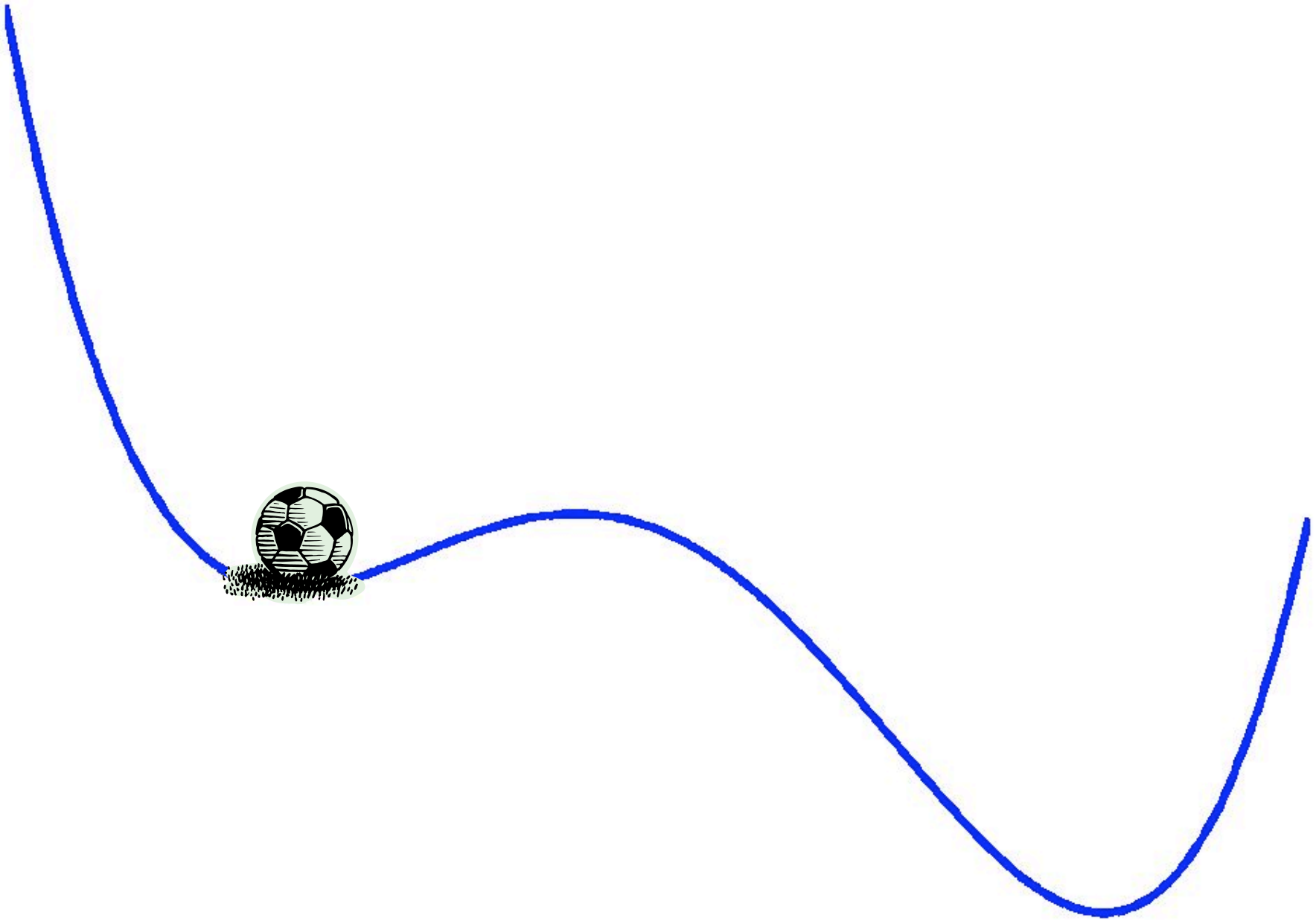
The apple cart is like a ball on a hill between two holes

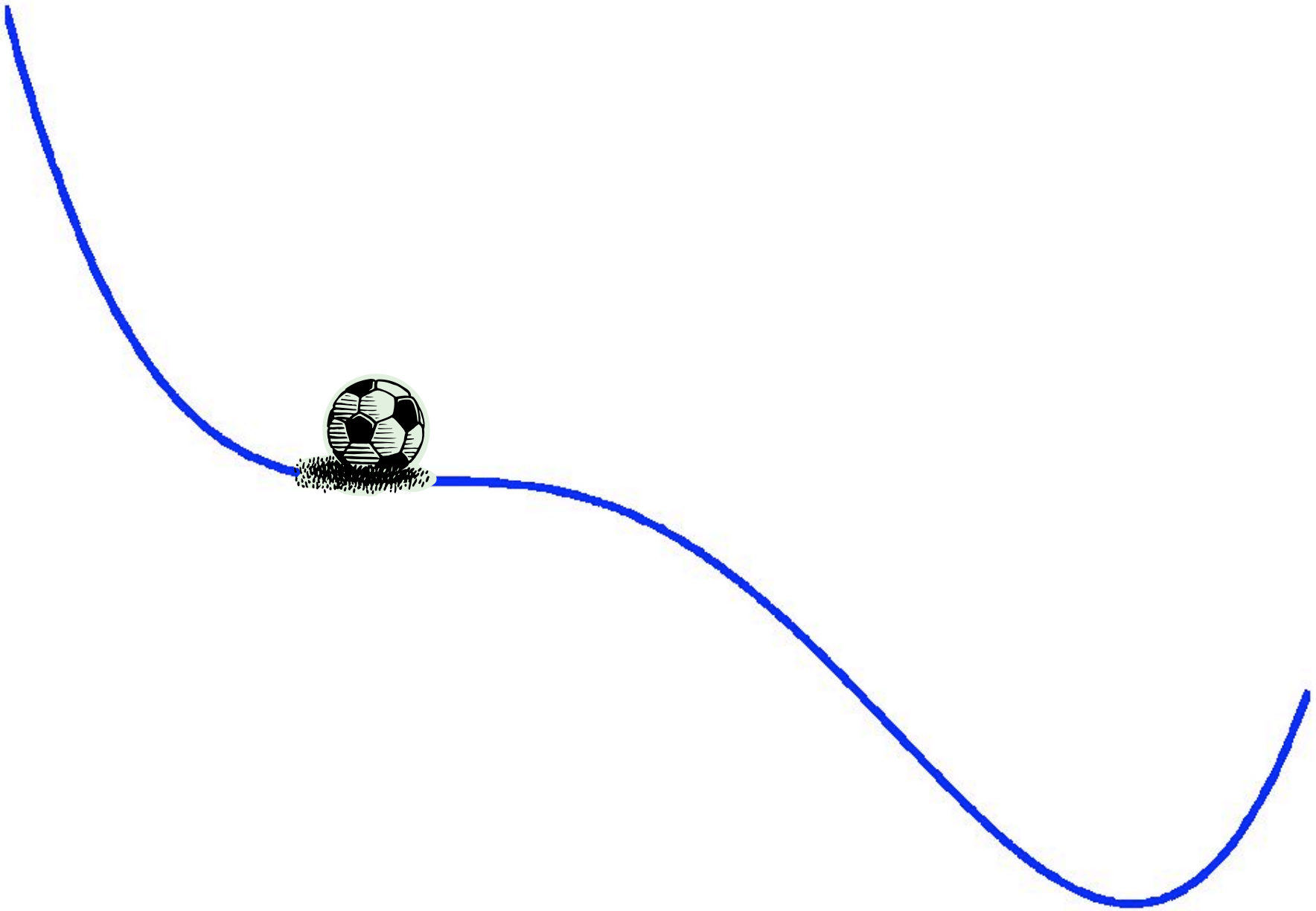


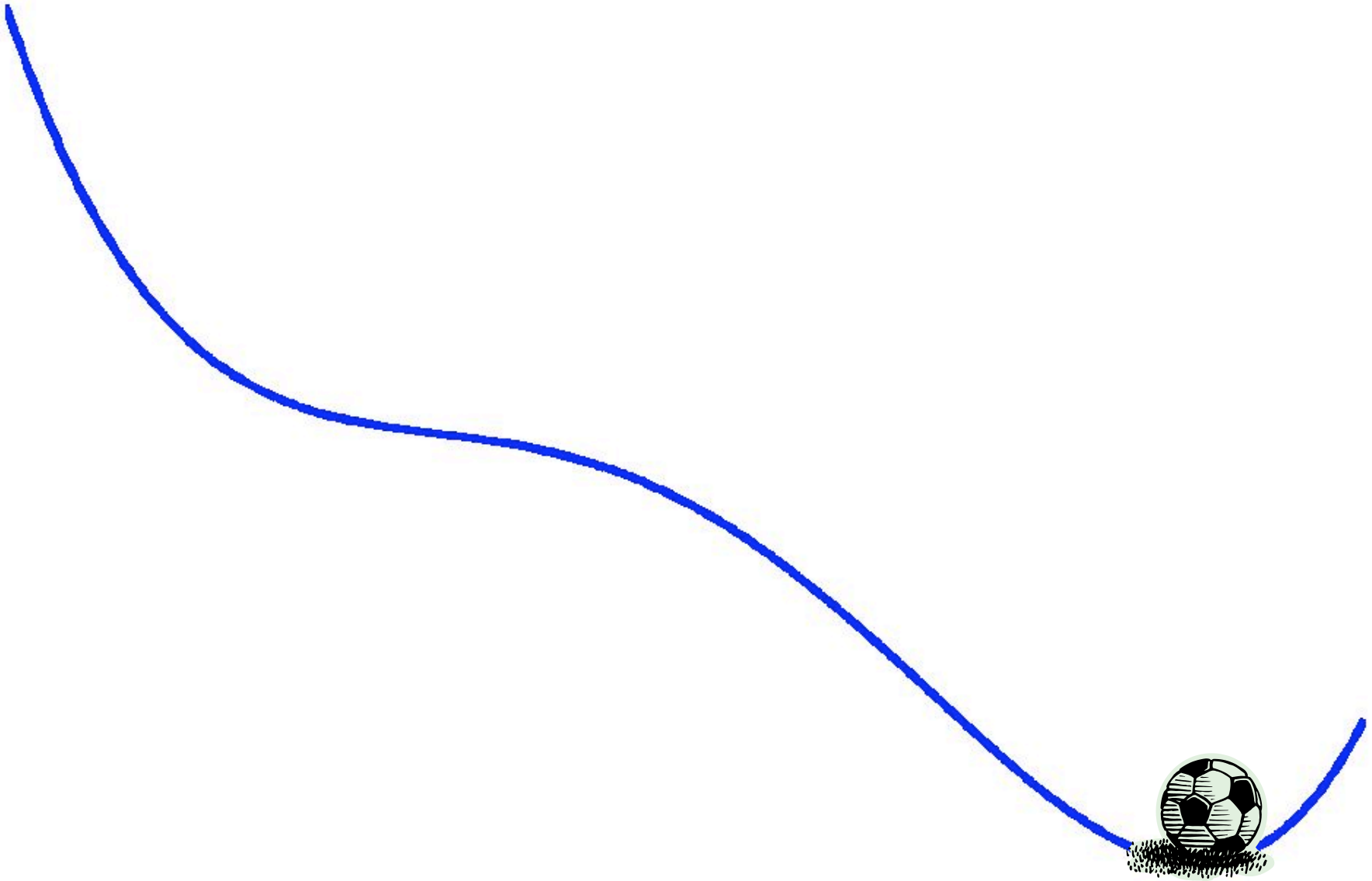
But .. If we change the shape of the mountain

We can change a stable state into an unstable state





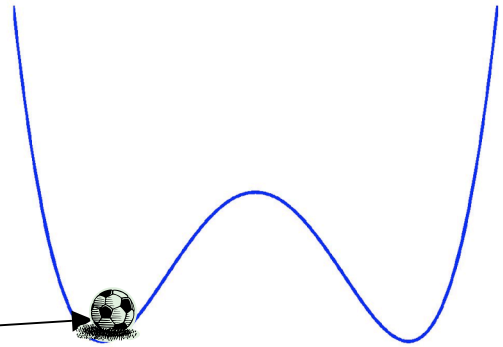




NOW … do the math!

Height of the mountain is V

Position of the ball is x



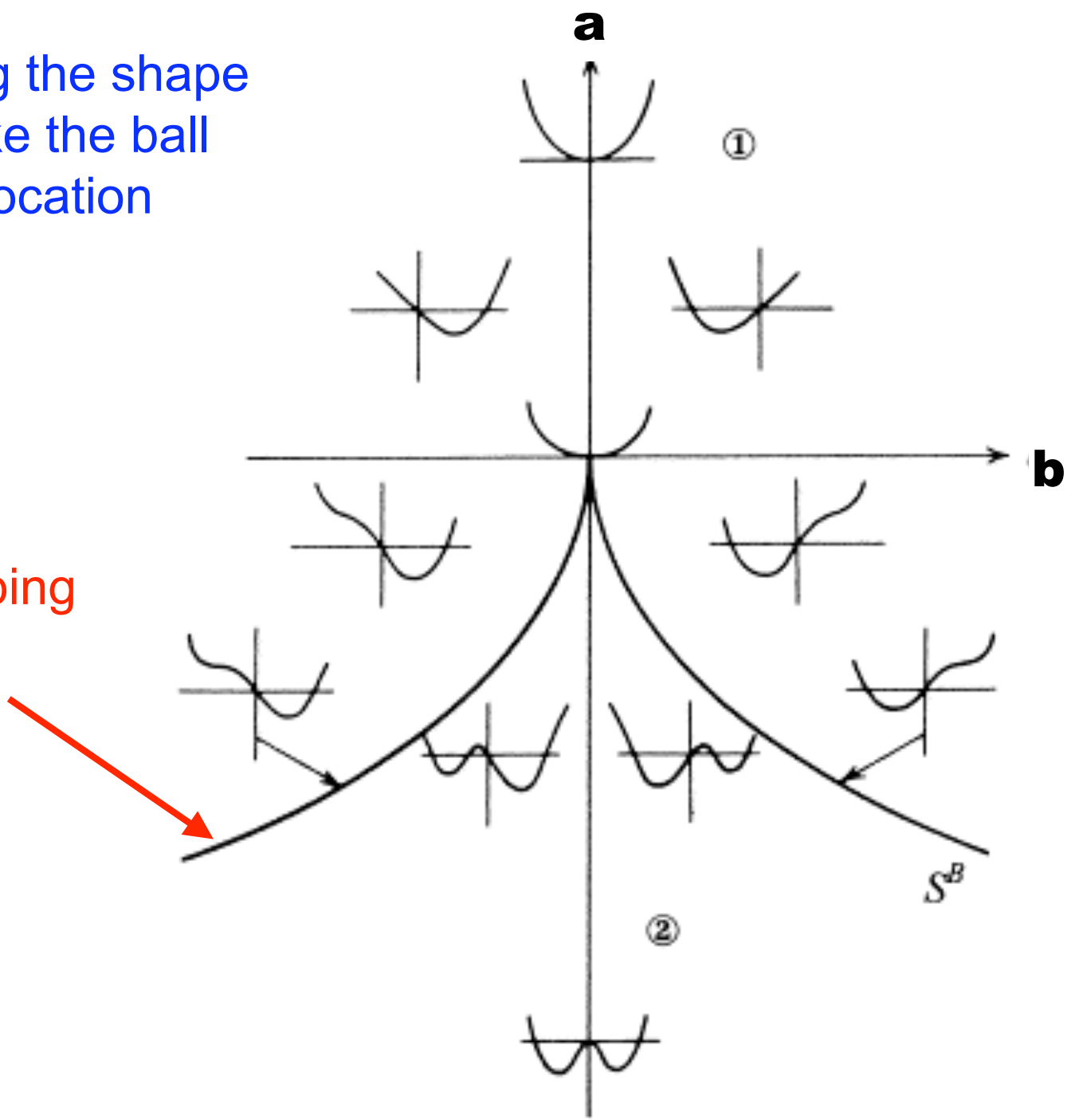
Things that change with time a(t) and b(t)

$$V = x^4 + a(t)\,x^2 + b(t)\,x$$

In the examples b(t) was changing

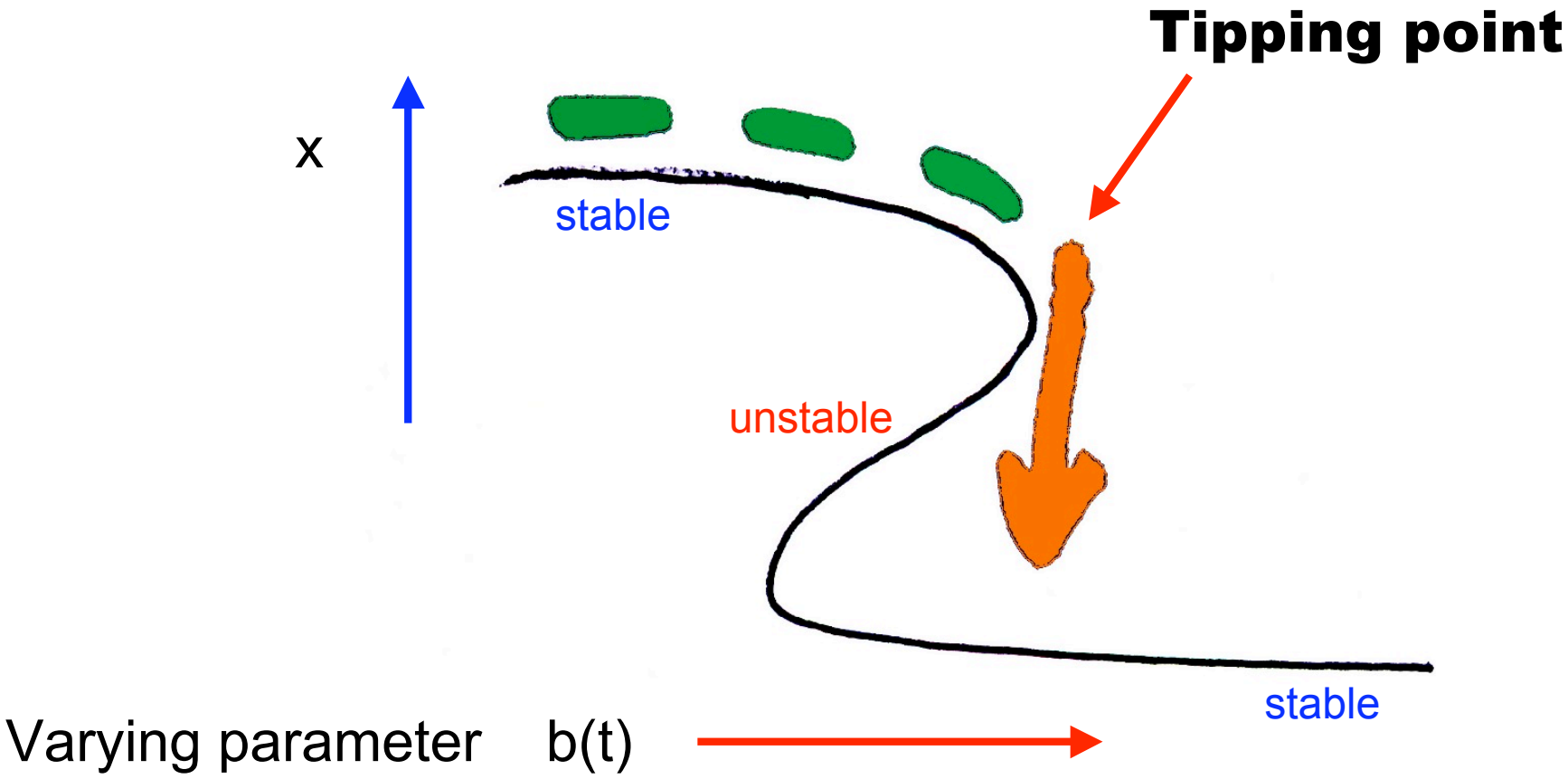
By changing the shape we can make the ball change its location suddenly

Here be tipping points



Ball's position x satisfies the equation

$$3x^3 + 2a(t)\,x + b(t) = 0$$

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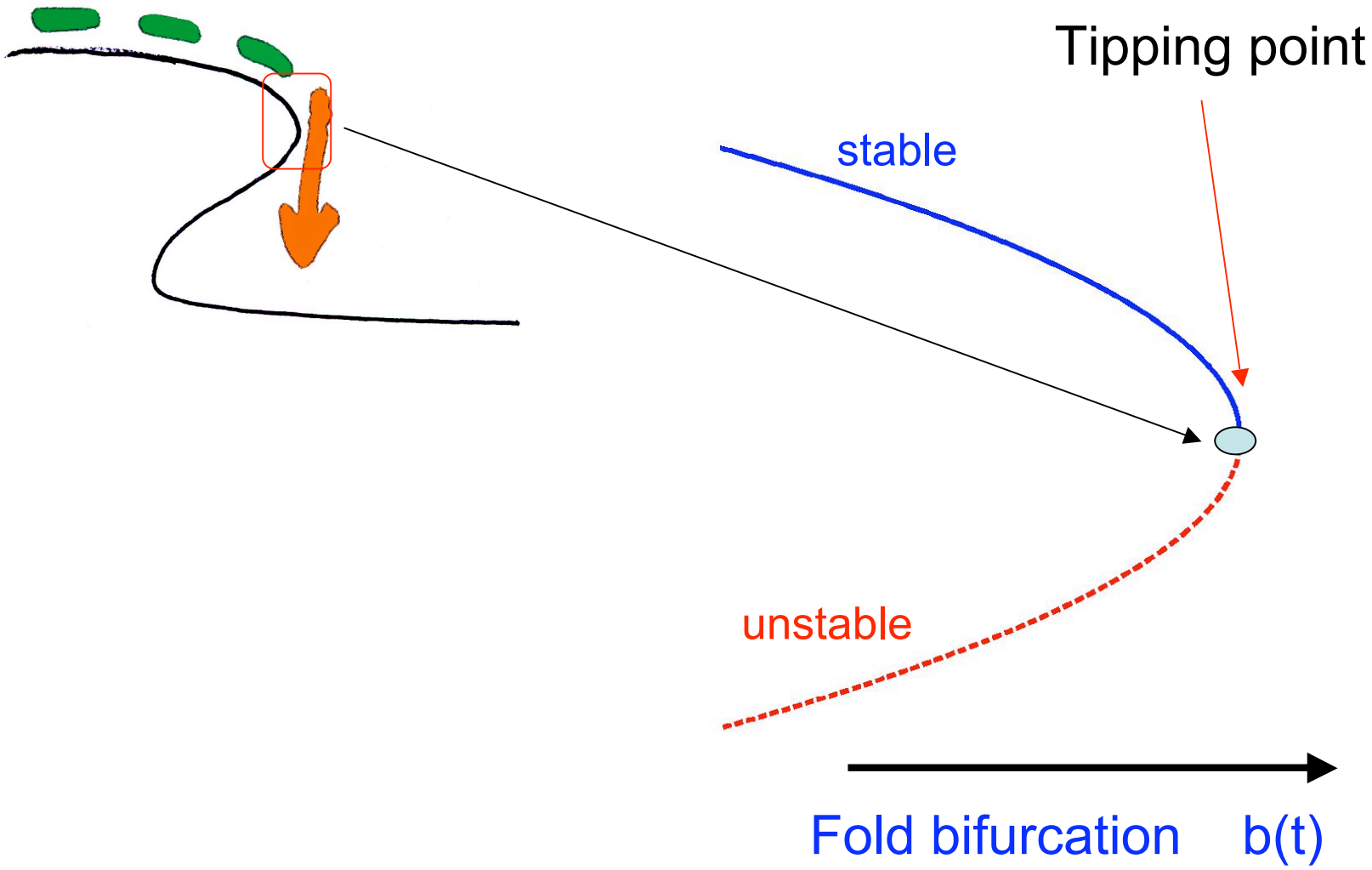
AS IF HITTING AN ICEBERG WASN'T SURREAL ENOUGH...
WORLD ECONOMY

Close-up to a tipping point



Quadratic equation: archetype of a tipping point

Equilibrium satisfies the quadratic eqn

$$b(t) + x^2 = 0$$

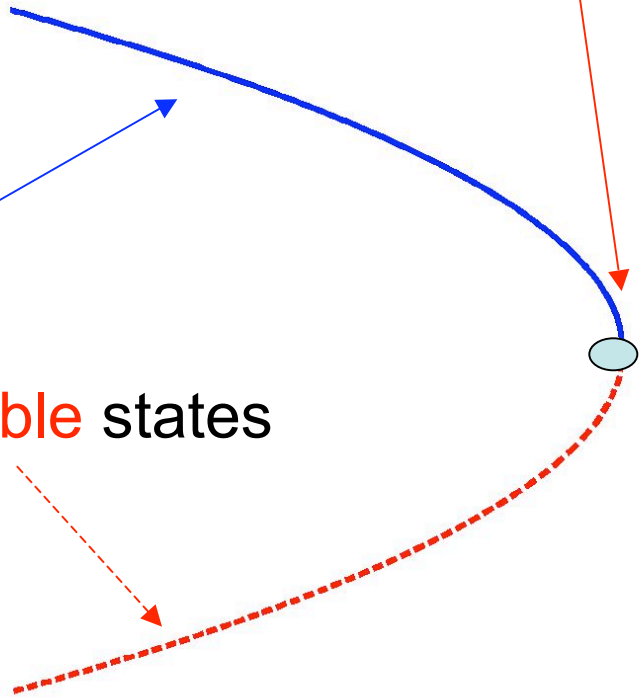
Studied by the Babylonians

Two roots if b negative

or none if b positive

Tipping point

Tipping point if b = 0



Roots: Stable or unstable states

None:

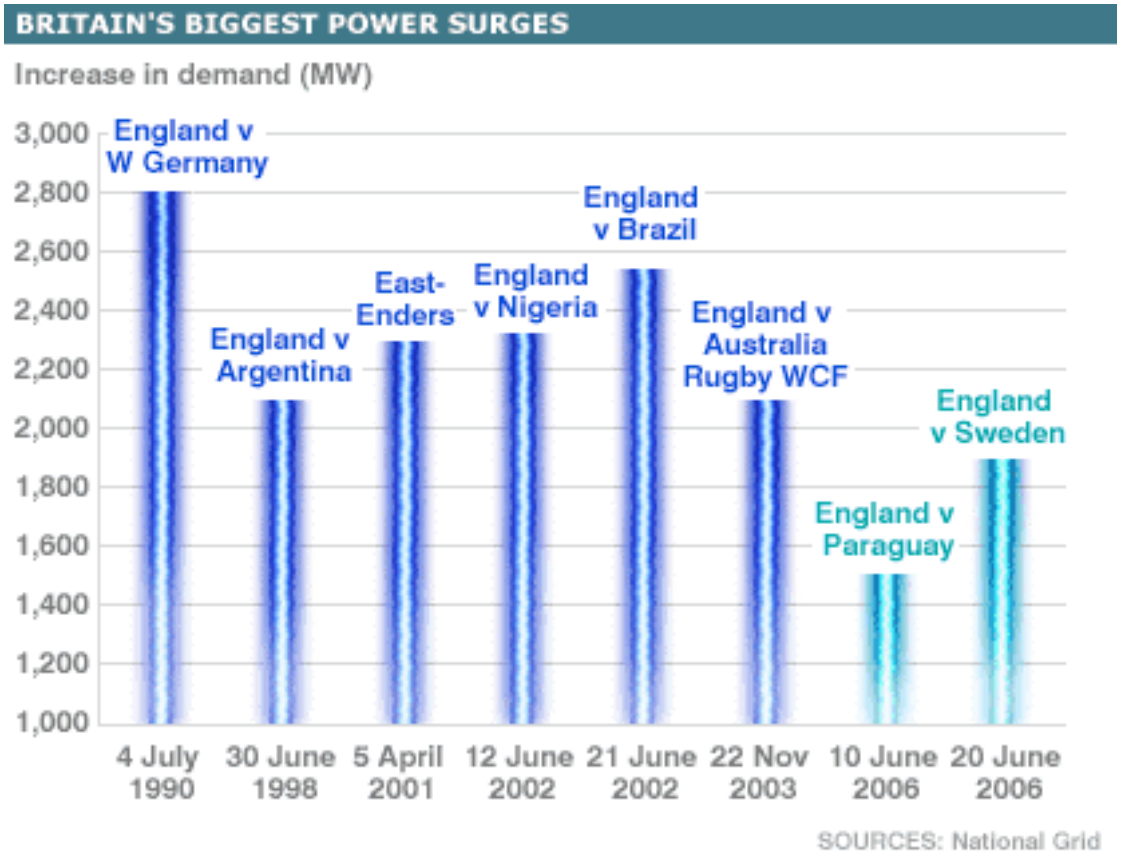
Major changes

Example: World Cup 1990: Near Miss!

England vs. West Germany

At the end of the match, power surged by 2.8 GW

11% of total capacity or 1 million Kettles



Voltage

Power drain

An example from the kitchen: Fluorescent light

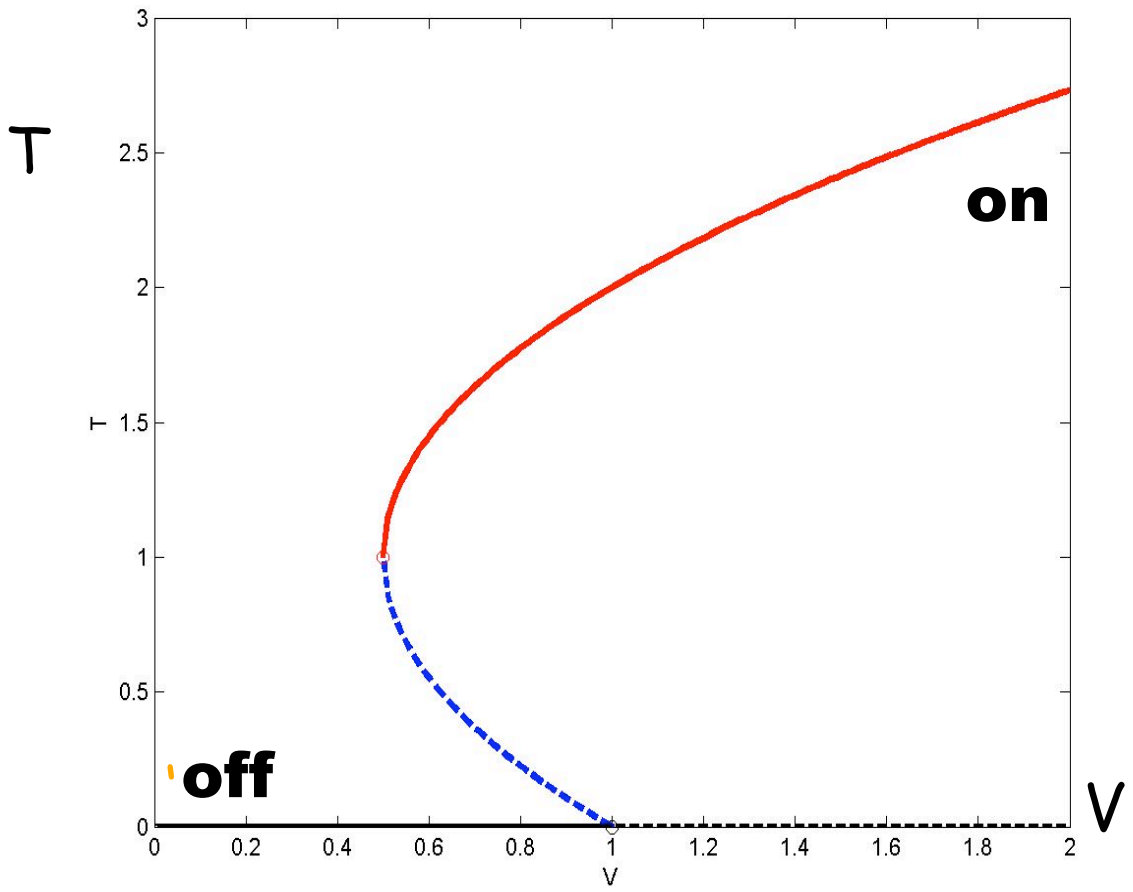
T_n Temperature at each AC cycle

V Applied voltage

$$T_{n+1} = V\,T_n + T_n^{\,2} - \frac{T_n^{\,3}}{2}$$

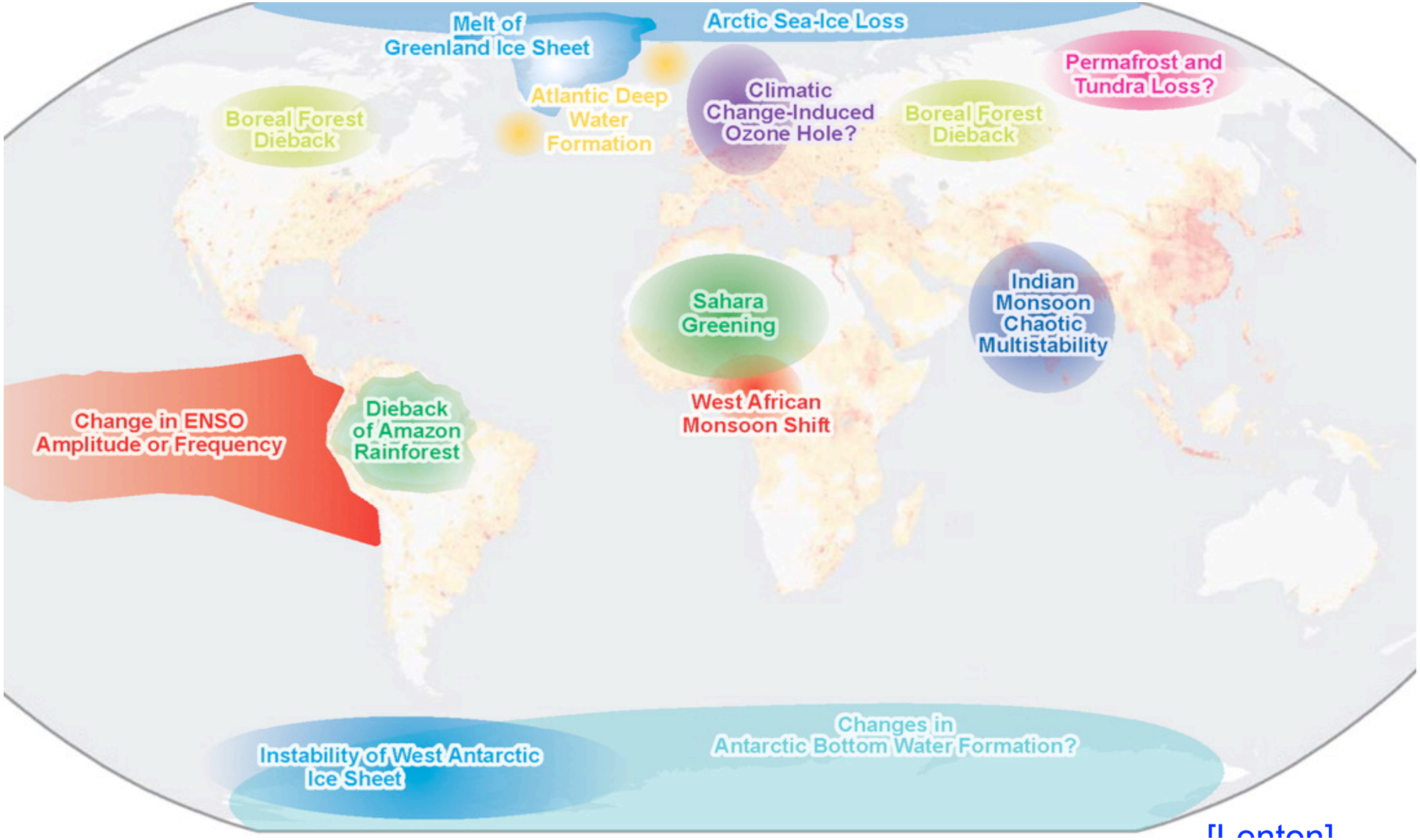
Q. Why do fluorescent tubes need a starter?

$$(V-1)T + T^2 - \frac{T^3}{2} = 0$$



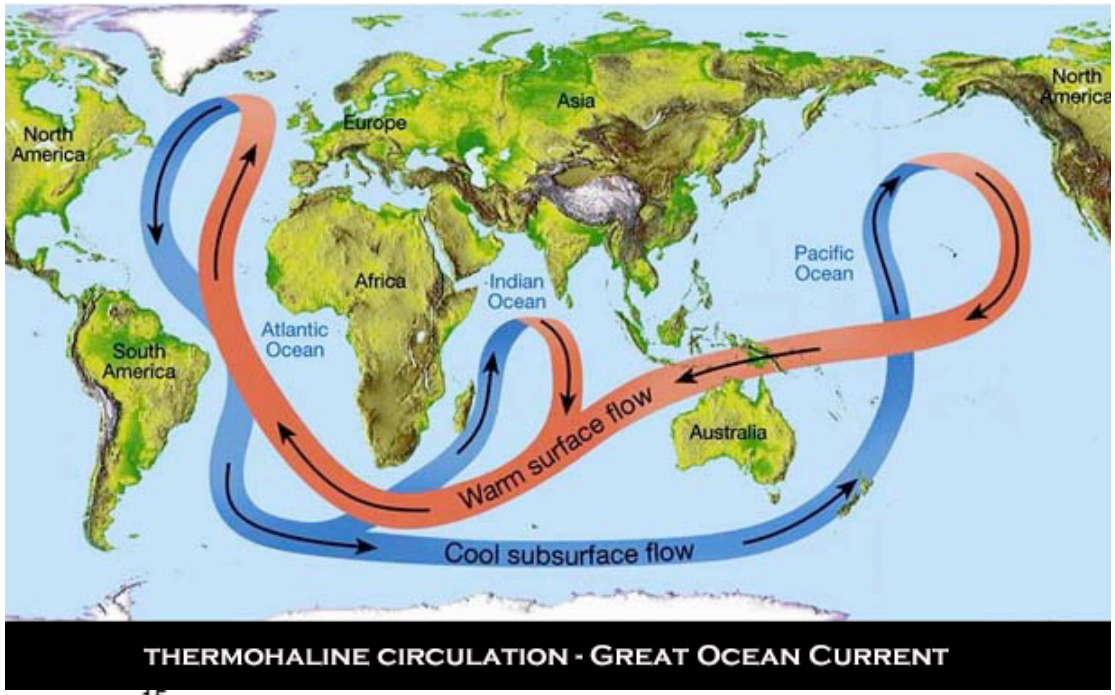
Potential Tipping Points In The Climate:

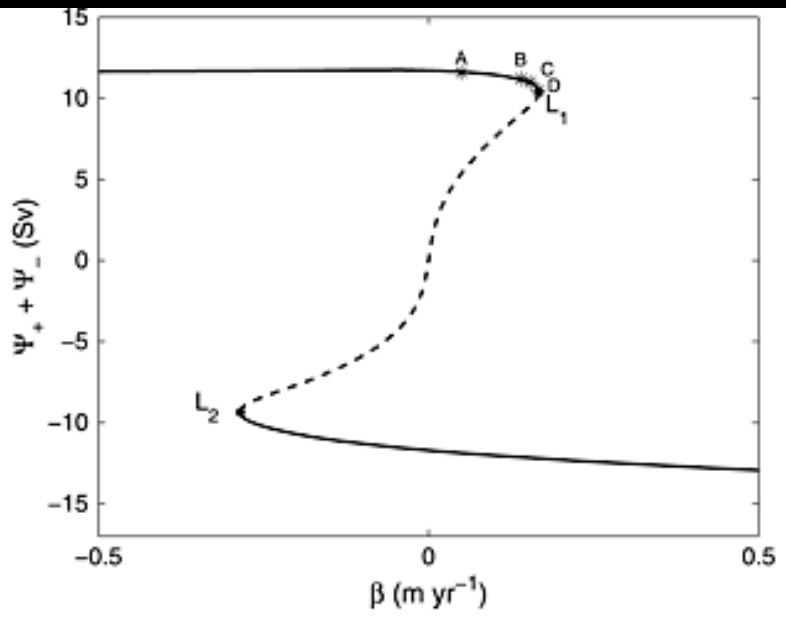
What many people are worried about!



[Lenton]

Shut down of the Gulf Stream?



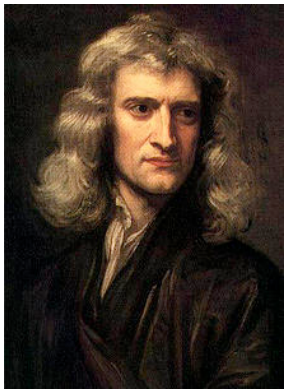


Fresh water flux

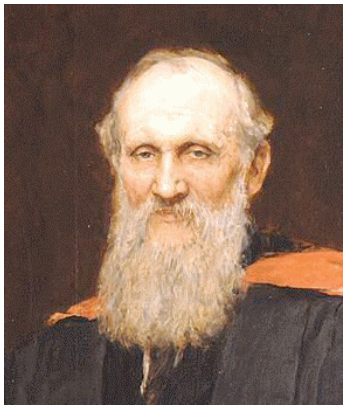
[Dijkstra et. al]

To study these tipping points we need climate models

Take laws of physics



Motion



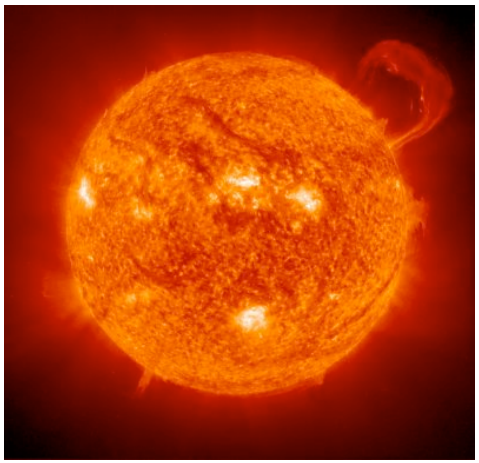
Heat

Turn them into mathematical equations

Inform them with data

Solve these on a supercomputer to try to predict the climate

Let's see if we can forecast the climate and ice cover with a simple climate model

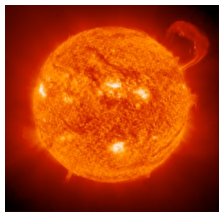


Heat into space

Heat from Sun: S

Earth's mean temperature: T

Heat absorbed $\longrightarrow (1-a)S$



a Albedo: How well the earth reflects the Sun's rays

Heat radiated away $\longrightarrow e\sigma T^4$

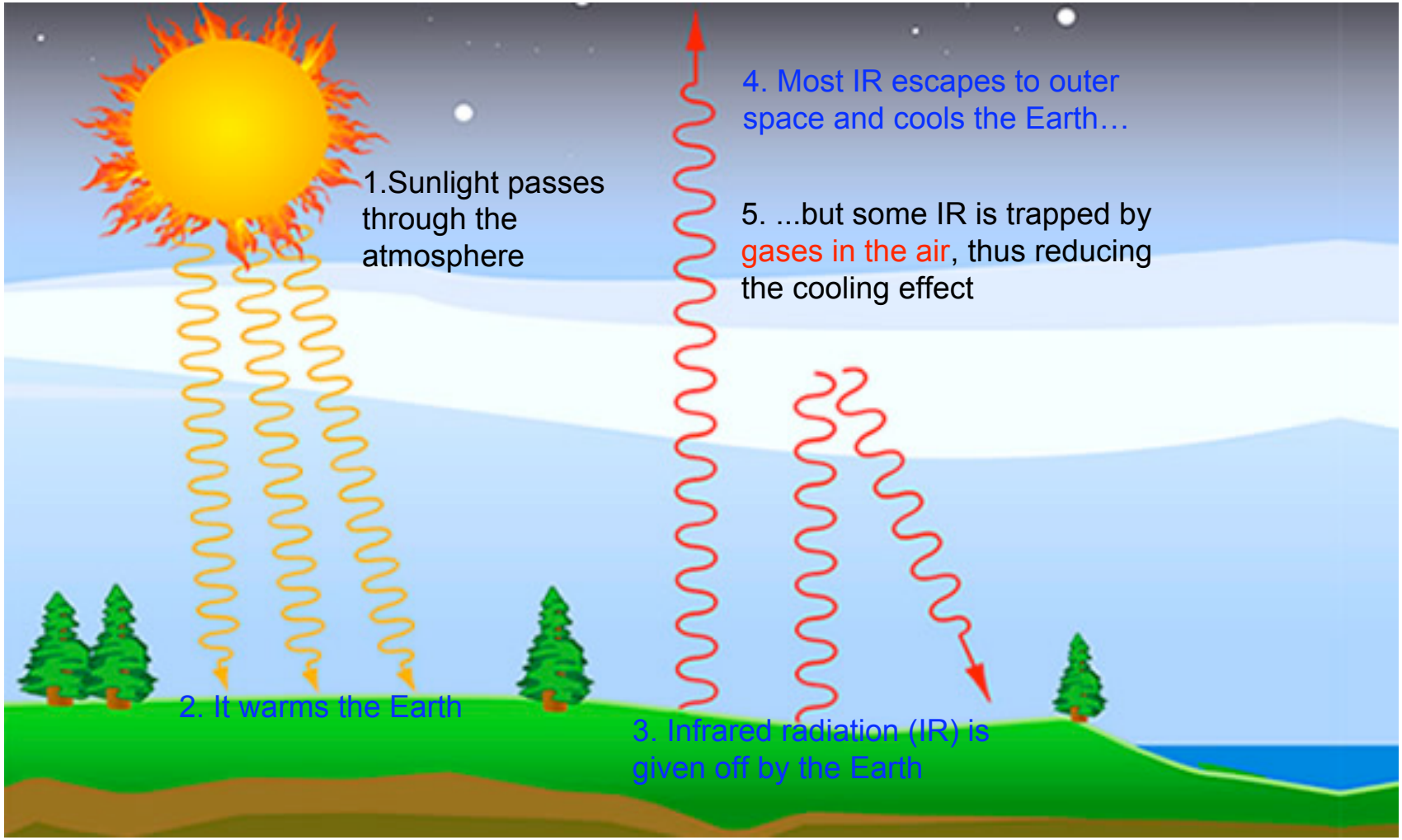
e emissivity: How much energy is radiated into space

Balance these to give a simple climate model

$$e\sigma T^4 = (1-a)S$$

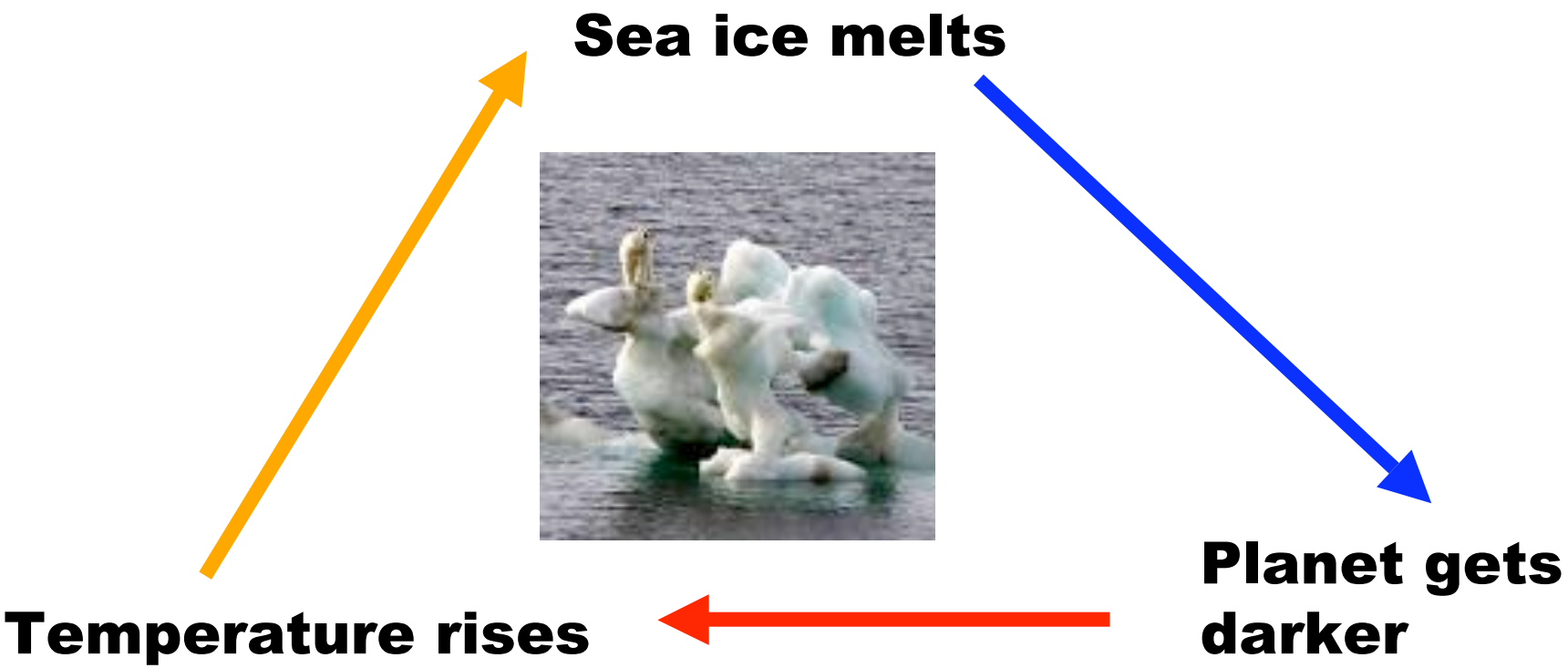
The greenhouse effect

Emissivity e decreases as CO2 increases. e approx 0.55



Prediction: T increases if a decreases

Leads to the albedo feedback loop

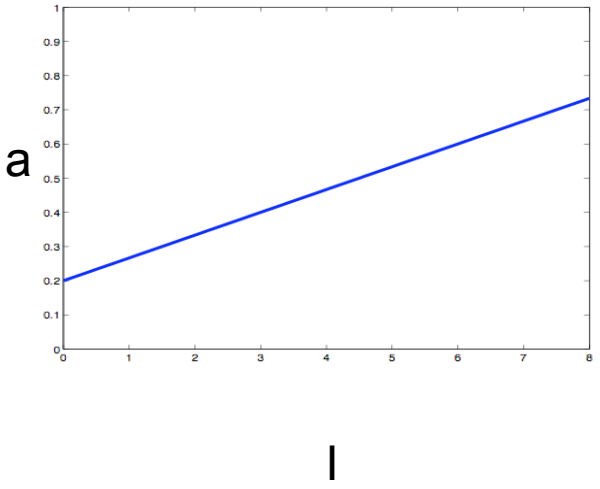


This means that future temperatures may be higher!

TIPPING POINT??

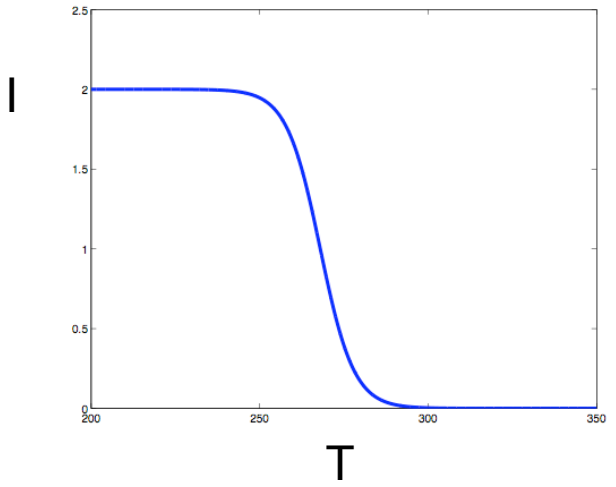
Albedo a decreases as ice content I decreases

$$a = \alpha + \beta I$$

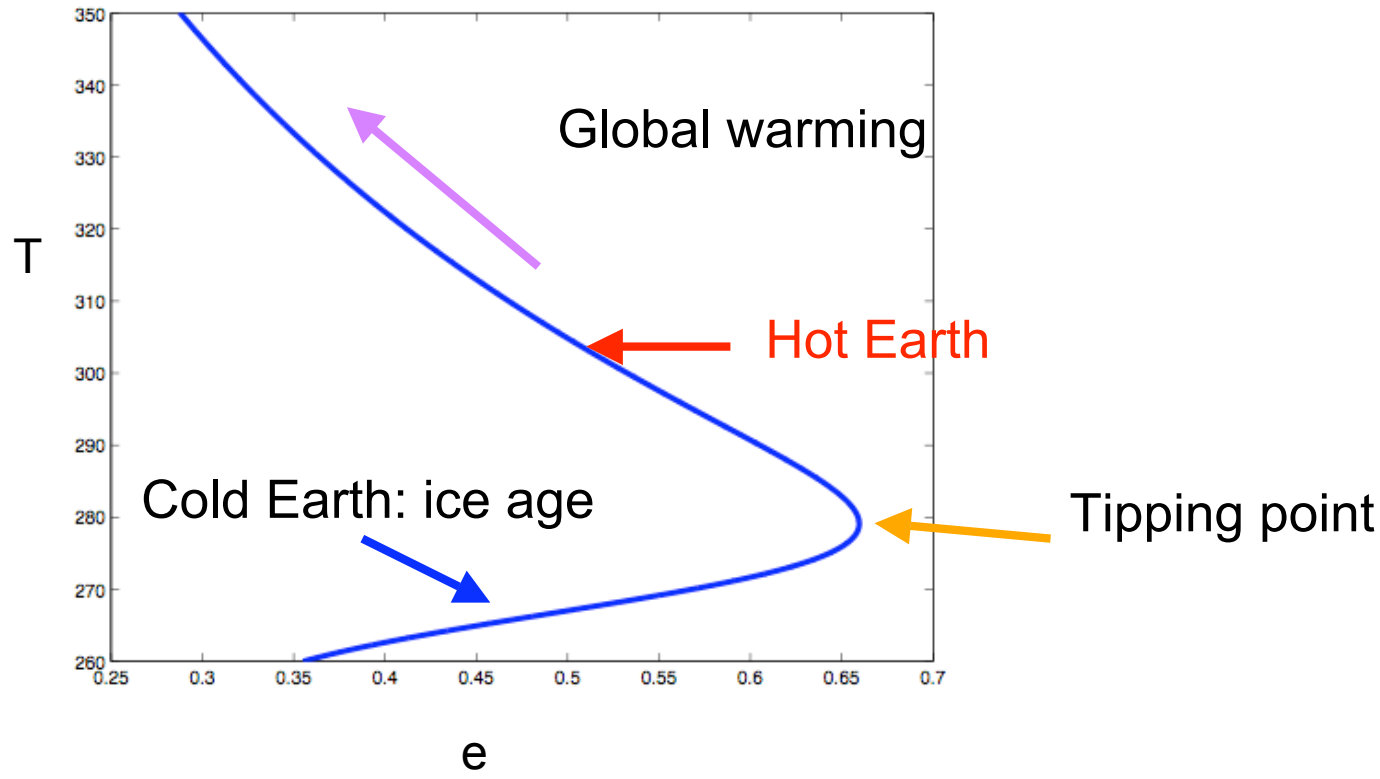


Ice content I decreases as Temp T increases

$$I = \gamma - \delta \tanh(T - T_0)$$



Putting the three equations together with measured values gives the picture

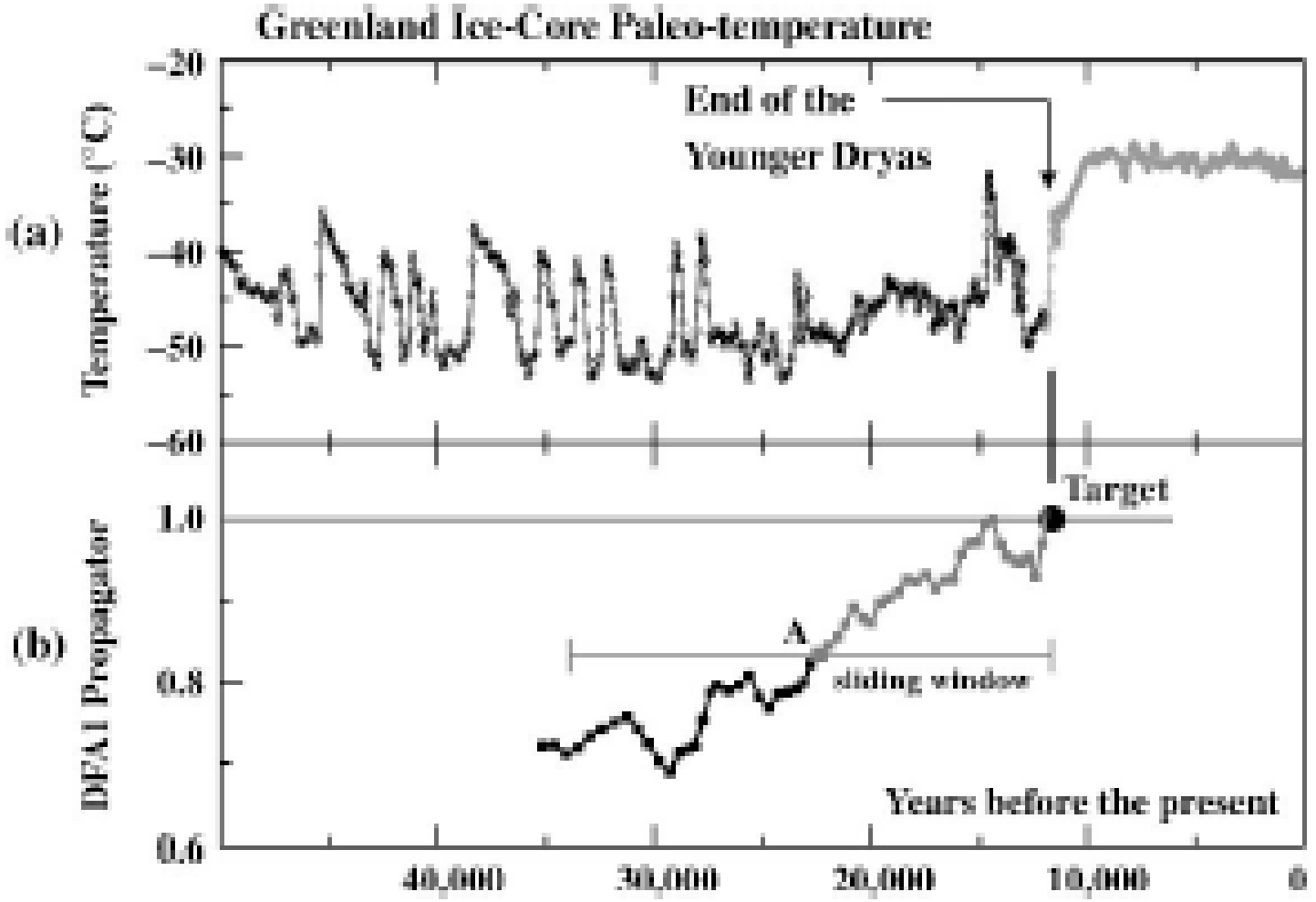


So .. Are we all doomed?

Early warning signs of a tipping point

- Slower recovery of the system to small deviations
- Erosion of the basins of attraction of the equilibrium states

Lenton's study of the end of the Younger Dryas Ice Age



But is every tipping event a fold?

Earthquakes

Non-smooth bifurcation

(friction)

MUCH less predictable

Or even …..

Conclusions

Do you still want to live in interesting times?

寧為太平犬，不做亂世人

pinyin: níng wéi tàipíng quǎn, bù zuò luànshì rén

"It's better to be a dog in a peaceful time than be a man in a chaotic period"

Maybe you can be an interesting dog!

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