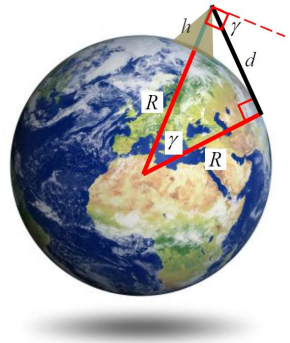
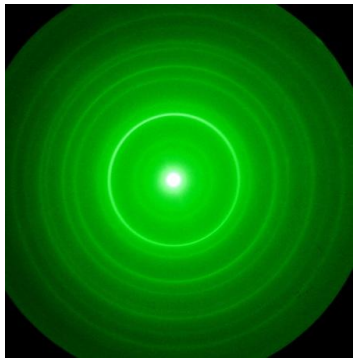


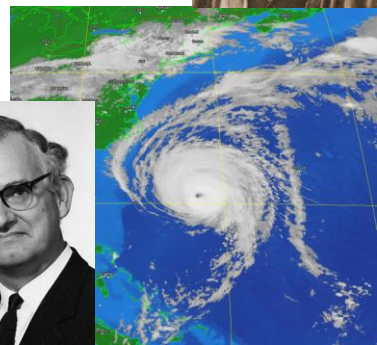
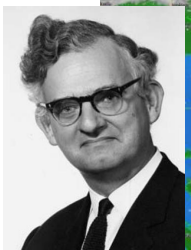










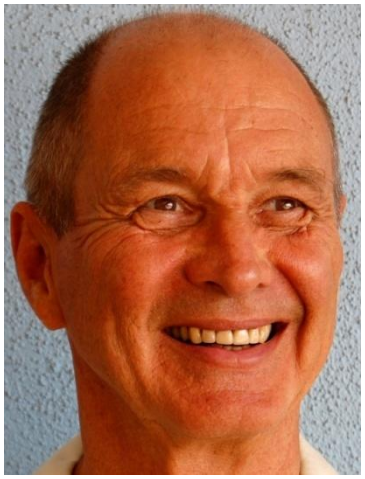
Science by Storytelling: The Pedagogical Power of Context

Andy French

February 2019

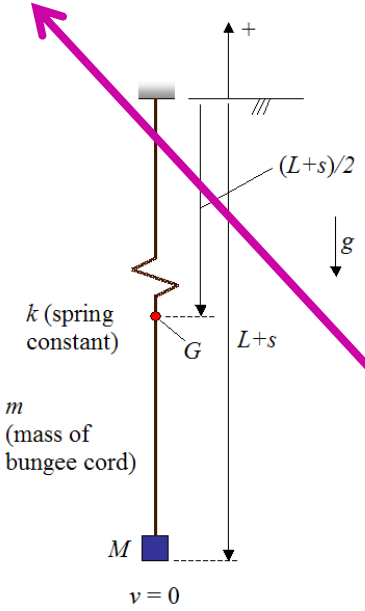
Activist ★
Having an experience

★ Pragmatist
Planning the next steps

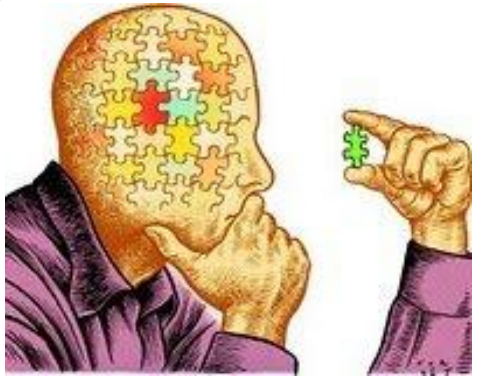


[David A. Kolb](#)
(1939-)

Reflector ★
Reviewing the experience



Theorist ★
Concluding from the experience



[Honey & Mumford's](#)
(1982) interpretation of Kolb's *Learning Styles*

Hang on a minute! I have patented this learning methodology!

Once upon a time.....

Axiom: From an early age, **stories** play a major part in our development of abstract reasoning, indeed how we comprehend *ideas*

- **Reflecting** on a direct or imagined experience
- Making **conclusions** and committing the experience to memory
- **Planning** the next steps (What happens in the next chapter?!)

In the beginning.....

.... was a short quiz

Guess the story from the opening sentence

[1 mark each, 10 marks available. Answers at the end. No scrubbing allowed]

A long time ago in a galaxy far, far away

A Mouse took a stroll through a deep dark wood

Mr and Mrs Dursley, of number four, Privet Drive, were proud to say that they were perfectly normal, thank you very much.

Two households, both alike in dignity, In fair Verona, where we lay our scene, From ancient grudge break to new mutiny, Where civil blood makes civil hands unclean.

It is a truth universally acknowledged, that a single man in possession of a good fortune, must be in want of a wife

A squat gray building of only thirty-four stories. Over the main entrance the words, CENTRAL LONDON HATCHERY AND CONDITIONING CENTRE, and in a shield, the World State's motto, Community, Identity, Stability.

Far Out in the uncharted backwaters of the unfashionable end of the Western Spiral arm of the galaxy lies a small unregarded yellow sun

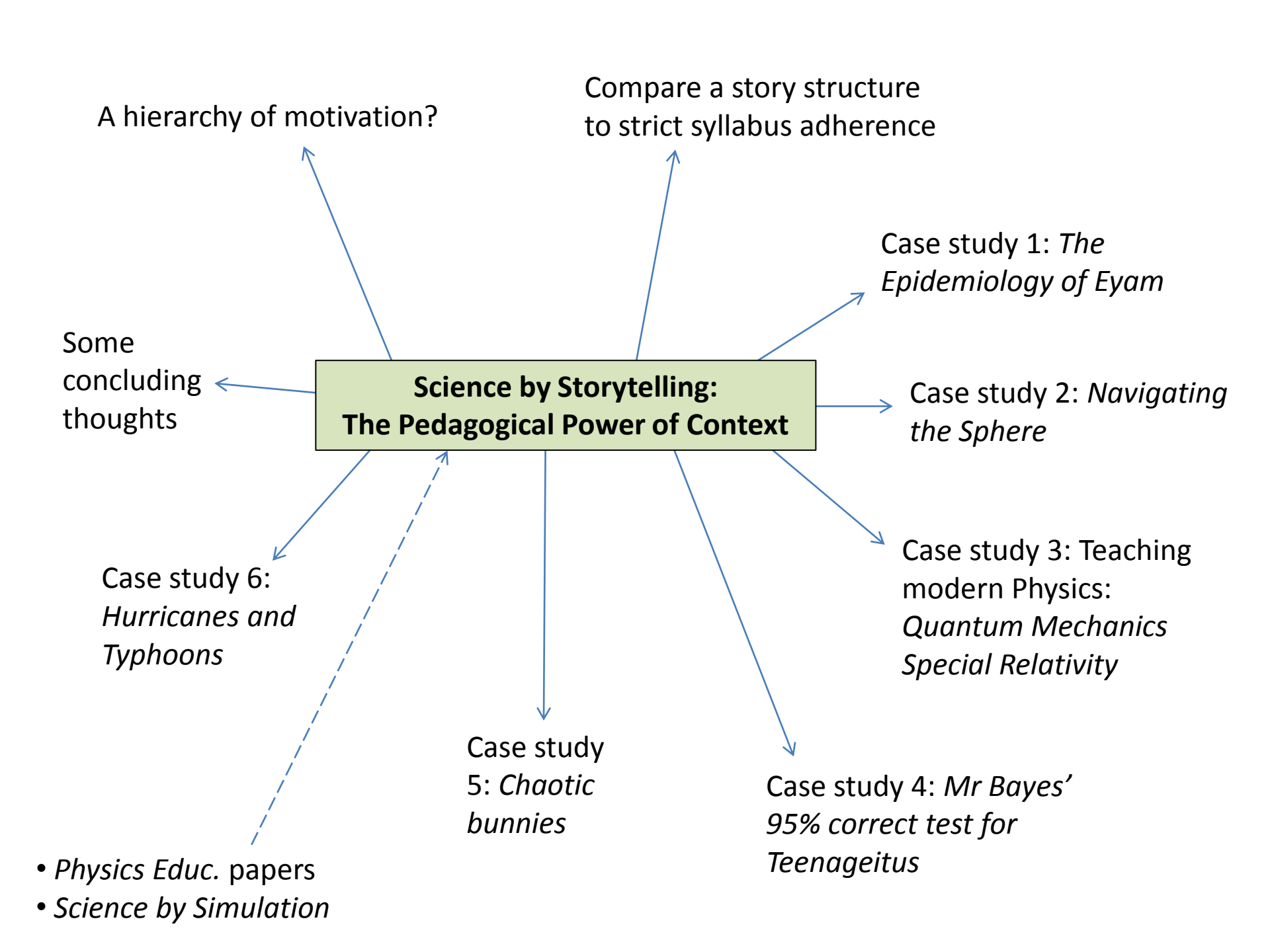
Dhritarashtra said: O Sanjaya, after my sons and the sons of Pandu assembled in the place of pilgrimage at Kurukshetra, desiring to fight, what did they do?

"So now get up."
Felled, dazed, silent, he has fallen; knocked full length on the cobbles of the yard. His head turns sideways; his eyes are turned toward the gate, as if someone might arrive to help him out. One blow, properly placed, could kill him now.

There was Eru, the One, who in Arda is called Ilúvatar; and he made first the Ainur, the Holy Ones, that were the offspring of his thought, and they were with him before aught else was made. And he spoke to them, propounding to them themes of music; and they sang before him, and he was glad.

ANSWERS

1. Star Wars (All of them! But firstly in Episode IV: *A New Hope*)
2. The Gruffalo
3. Harry Potter and the Philosopher's Stone
4. Romeo and Juliet
5. Pride and Prejudice
6. Brave New World
7. The Hitch Hikers Guide to the Galaxy
8. The Bhagavad Gita
9. Wolf Hall
10. The Silmarillion


A hierarchy of motivation?
Compare a story structure to strict syllabus adherence
Case study 1: *The Epidemiology of Eyam*
Some concluding thoughts
Science by Storytelling: The Pedagogical Power of Context
Case study 2: *Navigating the Sphere*
Case study 3: Teaching modern Physics: *Quantum Mechanics Special Relativity*
Case study 6: *Hurricanes and Typhoons*
Case study 5: *Chaotic bunnies*
Case study 4: *Mr Bayes' 95% correct test for Teenageitus*
• *Physics Educ.* papers
• *Science by Simulation*

A hierarchy of motivation?

Be inspired
This is really interesting, I can't resist having a go at it. Who cares what else is happening!

Compete
Compare and despair in relation to peers, siblings, family, reputation, expectation...

Don't mess up
Fear of cultural/scholastic/professional failure

Maslow's foundation: Desire to meet basic physical needs (warmth, food, shelter etc)

Compare a story structure to strict syllabus adherence

Story

Set the scene. Main characters. Heroes, villains, beasts...
Define the problem, quest, challenge
Overcome challenges ingeniously, or via serendipity. Use honed craft, or develop new tricks
Live happily ever after ....
.... Or an unexpected problem is revealed, which motivates another story!

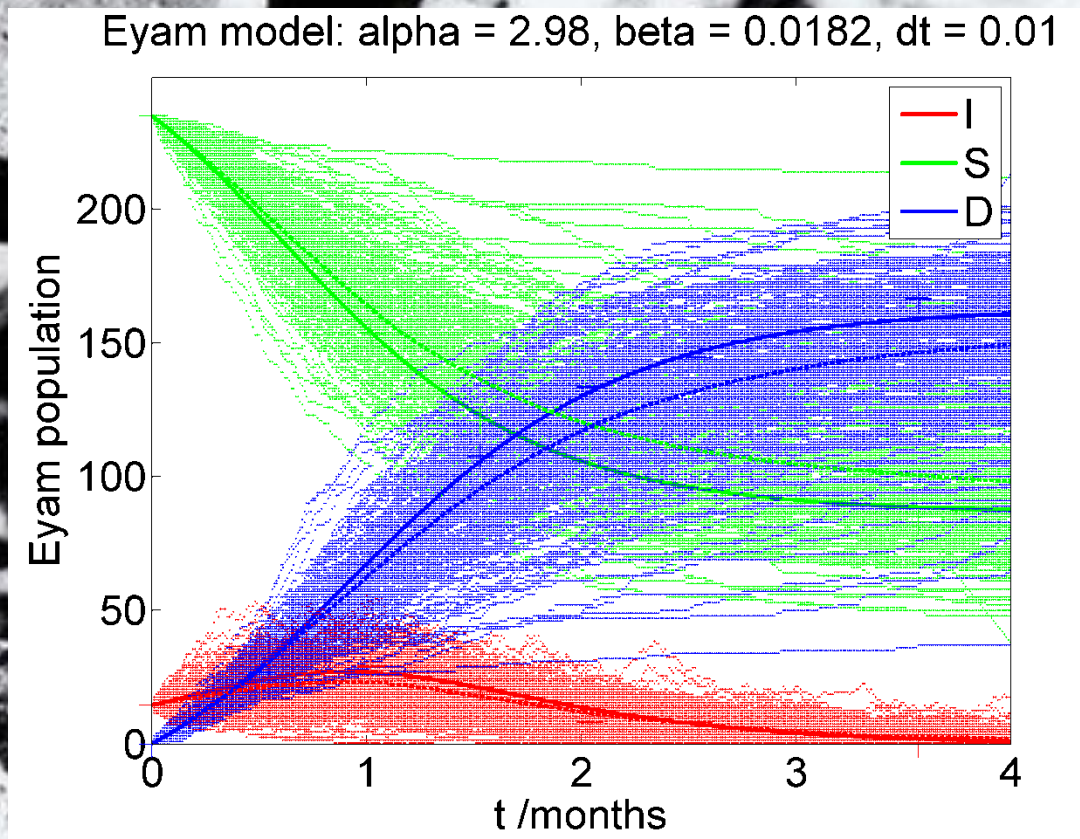
- Ideas are placed in a rich context
- Easy to visualize and relate to
- Most stories directly involve the lives of people (or anthropomorphised animals!)

Syllabus*

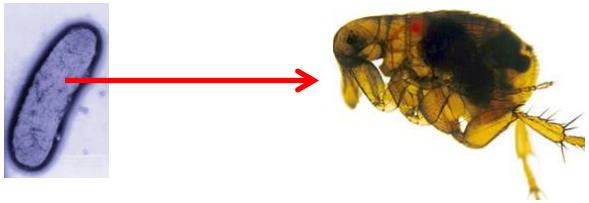
Here is a fact. It is in the exam, so learn it!
Here is a possibly related fact. Learn this too. It is very important.
Tomorrow we begin a new topic. It might be related to what we covered a month ago. Obviously you will remember what we did then.

*I'm deliberately being provocative here! Syllabuses are of course important structurally, but without stories I suggest they can be somewhat soulless.

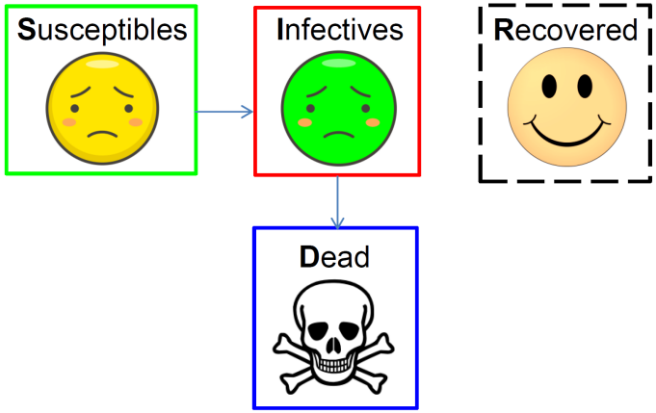
Epidemiology of *Eyam*: The Village of the Damned

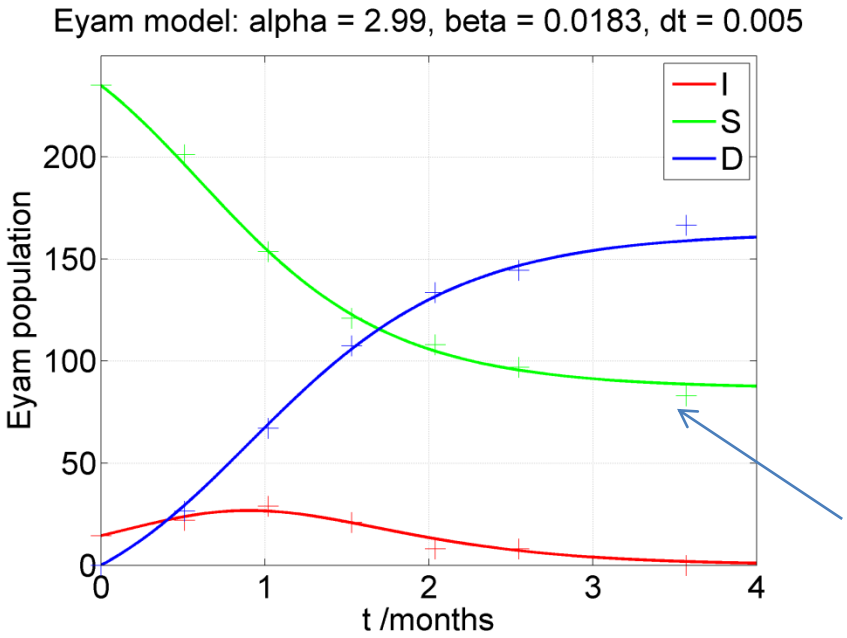


1665. A bale of damp cloth is delivered to the Derbyshire village of **Eyam**... George Viccars, the tailor's assistant, dries the cloth and releases fleas infected with *Yersinia Pestis* bacteria – **Plague**



Rector **William Mompesson** *quarantines* Eyam and records **Infected**, **Susceptible** and **Dead** populations *as time progresses*





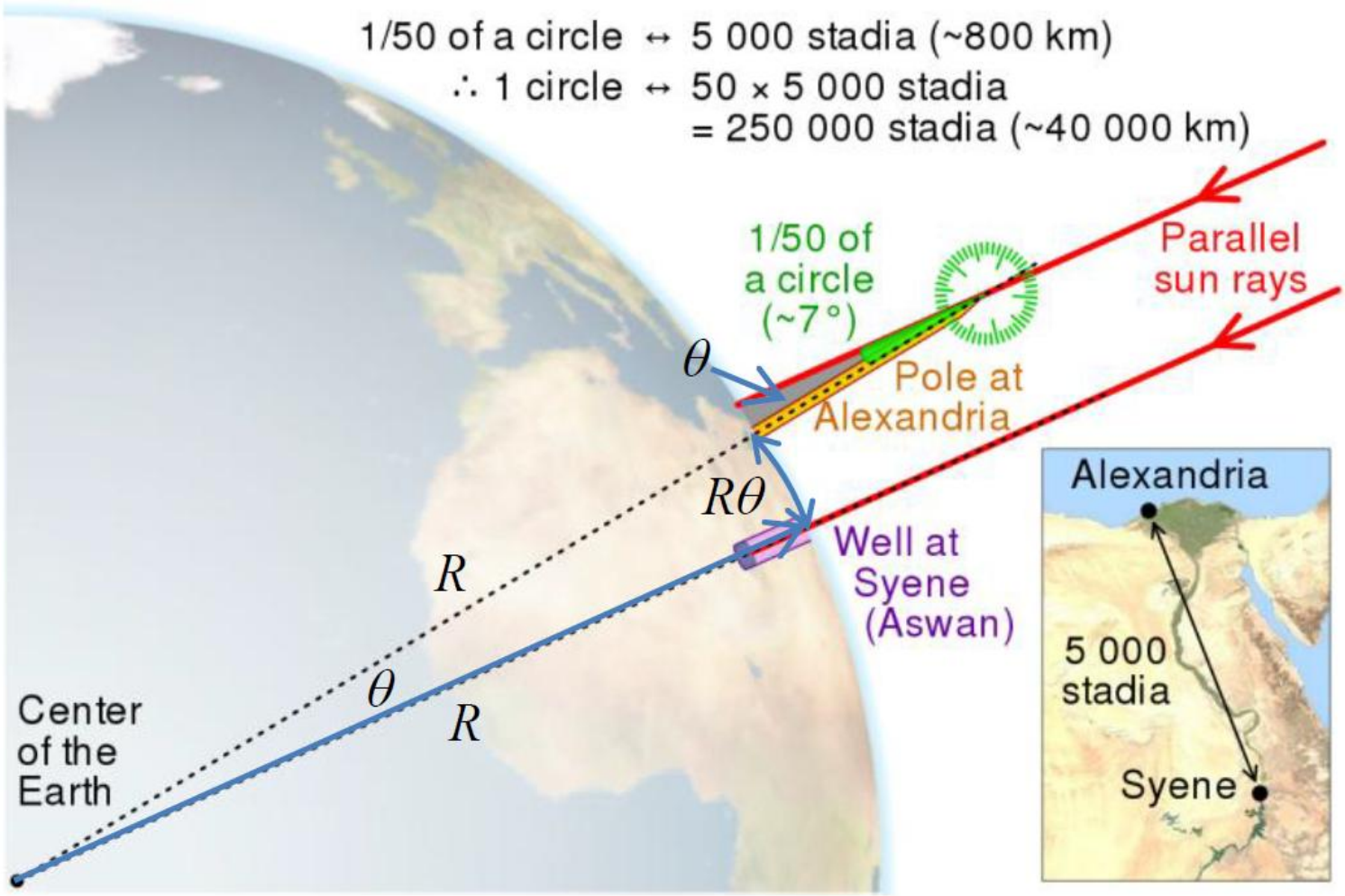
Can we develop a mathematical model to predict I,S,D vs time? What does this tell us about *Epidemiology* in general?

Calculus methods, differential equations numerical methods, line of best fit, iteration, loops ...

"How best to motivate students to expand their mathematical toolbox, and perhaps more importantly, gain experience of applying these ideas in the construction of quantitative models? A narrow focus on memorizing a long list of abstract procedures sufficient to pass an examination is a poor mechanism for producing the original thinkers of the future. It is also particularly harsh on those who have to struggle more than their peers to embed syllabus content in their minds. In this paper we celebrate the pedagogical power of context and storytelling, with the introduction of calculus ideas in an epidemiological scenario as an example."

The Pedagogical Power of Context: Iterative Calculus Methods and the Epidemiology of Eyam
(French et al 2018 J. Phys.Educ.)

Eratosthenes
276BC-194BC

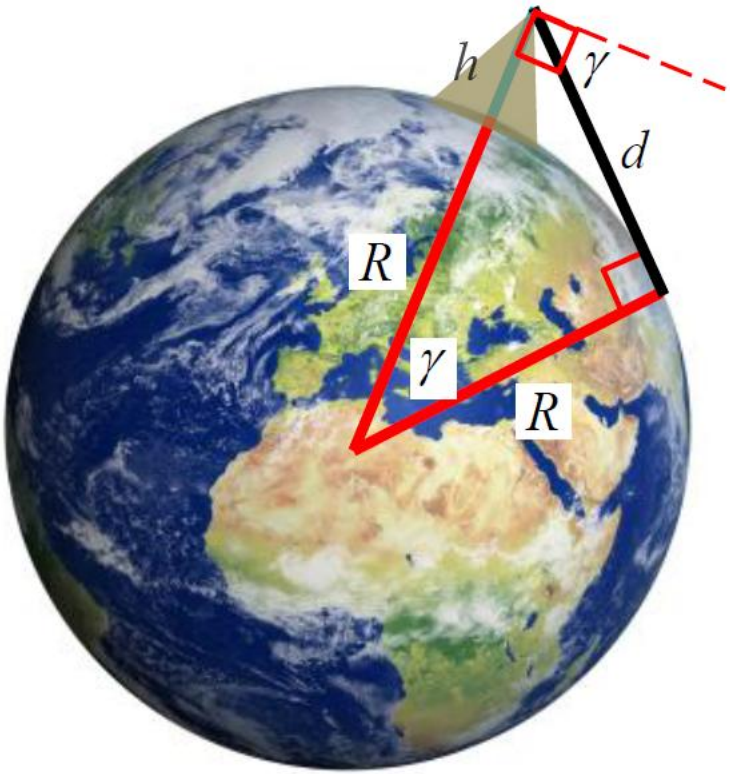


$R\theta \approx 5{,}000\,\text{stadia}$ $\quad 1\,\text{stadia} \approx 185\,\text{m}$

$$\theta \approx 7.2 \times \tfrac{\pi}{180}\,\text{rad} \quad \therefore R \approx \frac{5{,}000 \times 185}{7.2 \times \frac{\pi}{180}} = \boxed{7.36 \times 10^6\,\text{m}}$$

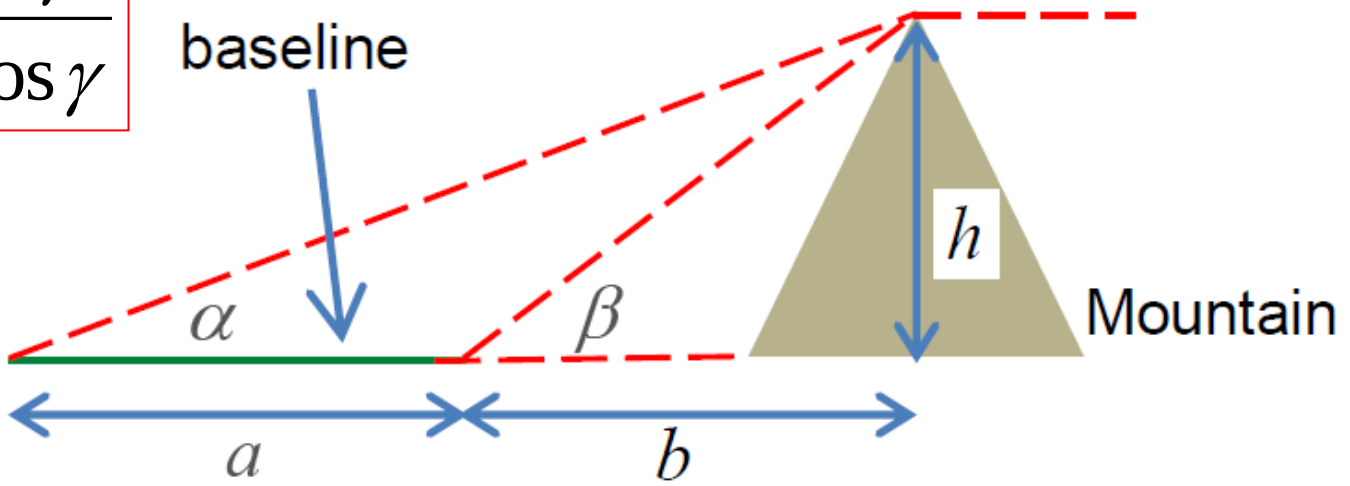
$$\frac{R - R_\oplus}{R_\oplus} = \frac{7.36 - 6.371}{6.371} \approx 16\%$$

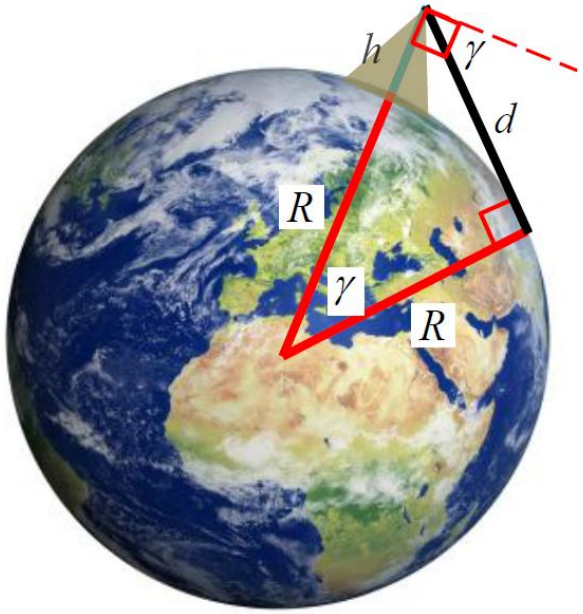
Navigating the Sphere

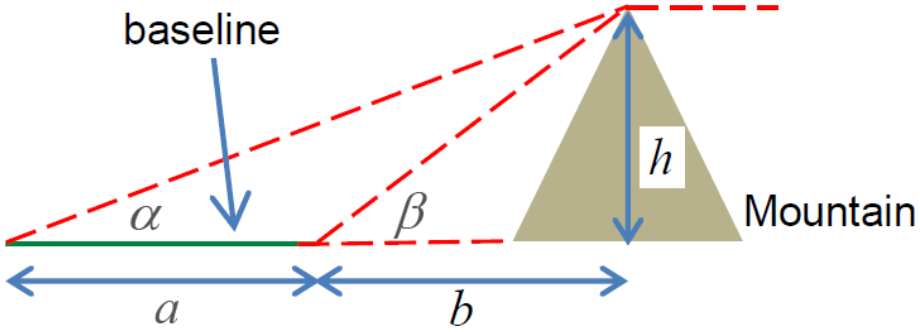


$$R = \frac{h\cos\gamma}{1-\cos\gamma}$$

Al Biruni
973-1050







$$a = 1{,}000\text{m}$$

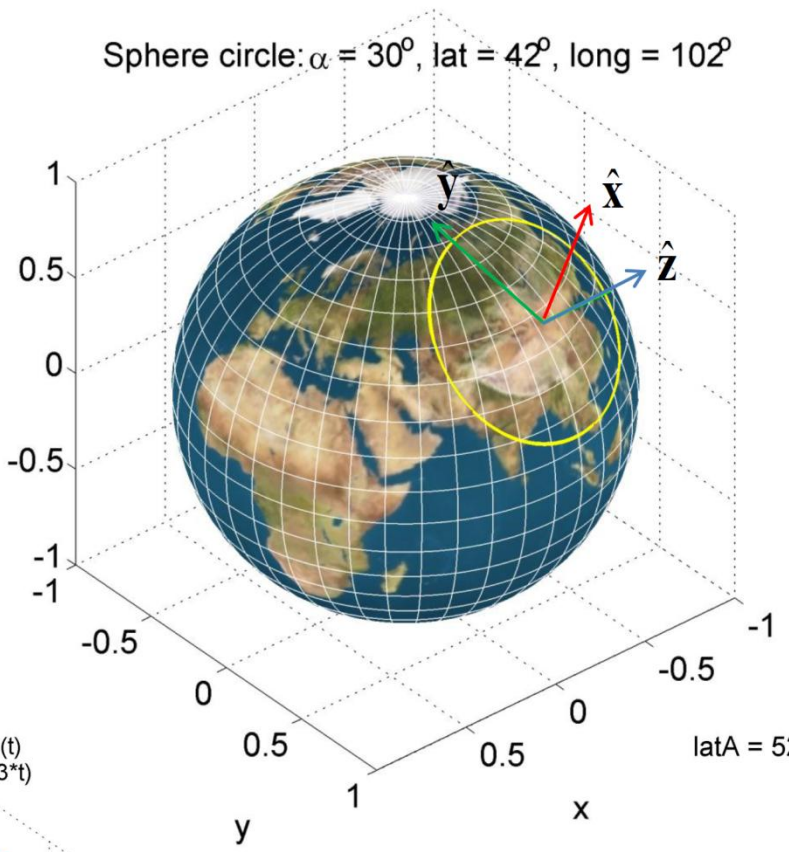
$$\alpha = 30.00^{\circ},\quad \beta = 45.00^{\circ}$$

$$\therefore h = 1{,}366\text{m}$$

$$\gamma = 1.19^{\circ} \quad \therefore \boxed{R = 6.33\times10^{6}\,\text{m}}$$

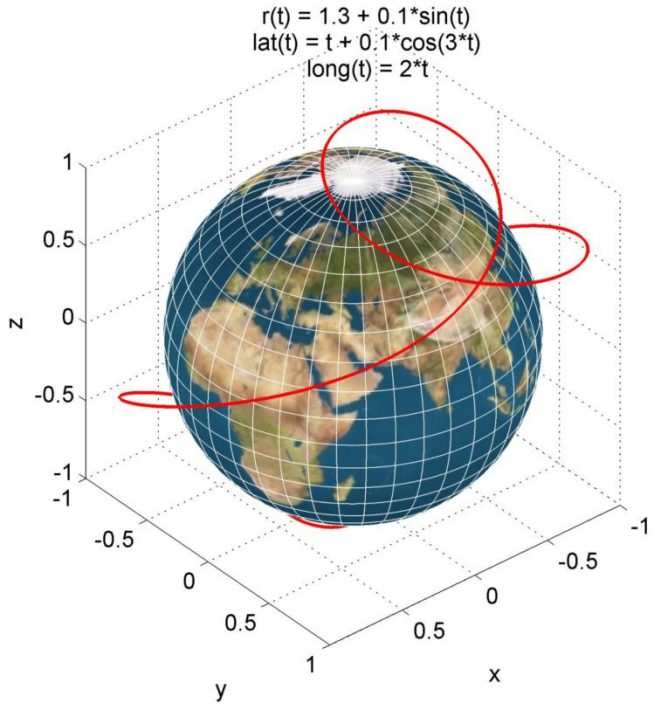
only 0.6% in error!

$$R_{\oplus} = 6.371\times10^{6}\,\text{m}$$

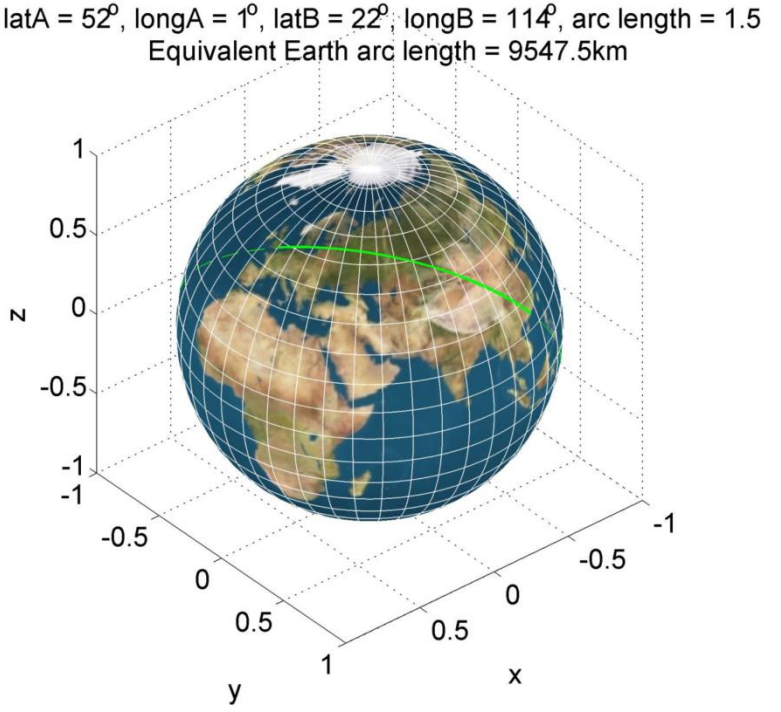


How do we draw a circle on a sphere?

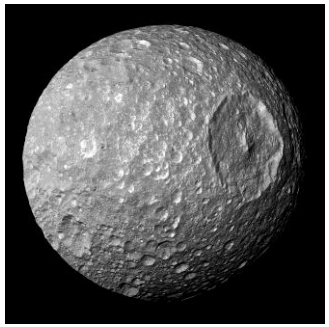
Aircraft routing



Satellite orbits



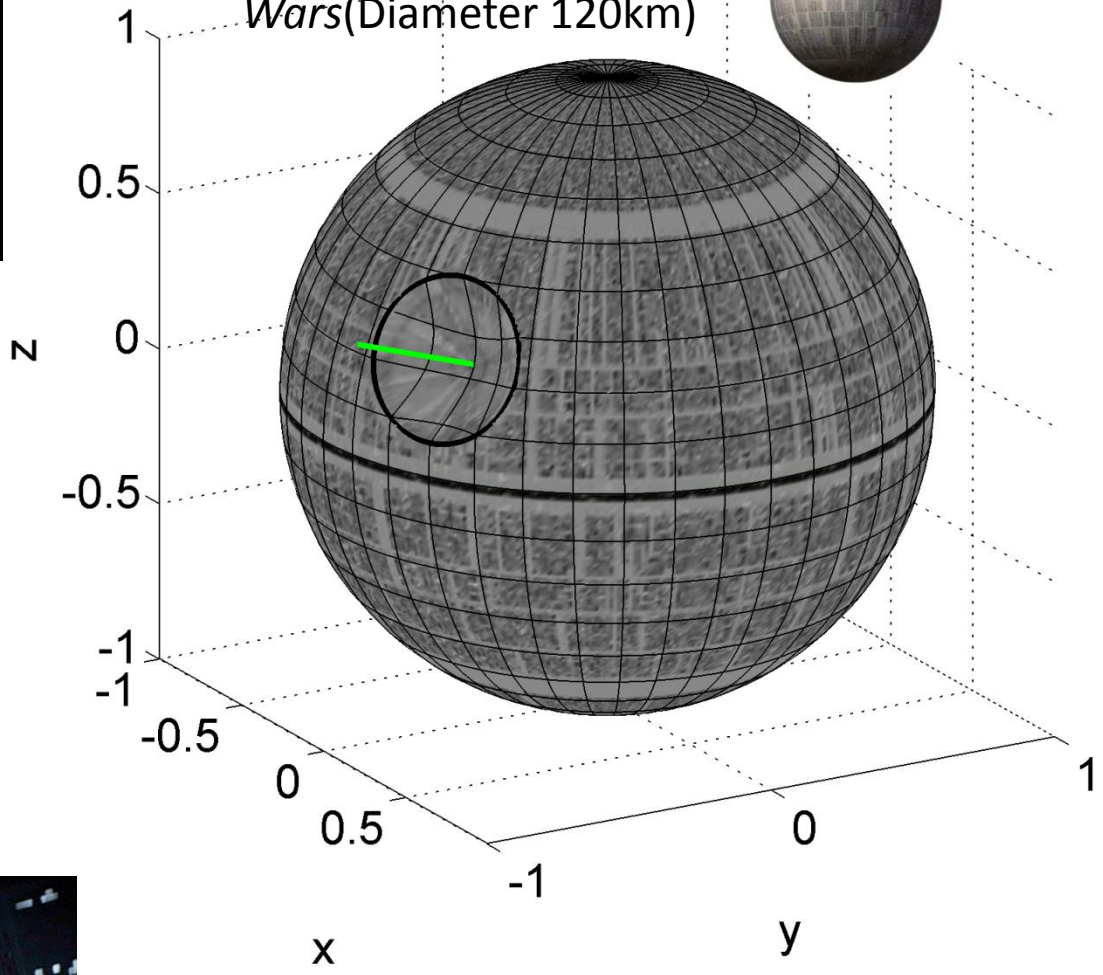
Plus an additional frivolous problem ....



Mimas – a Moon of Saturn (Diameter 396km)

Death Star: $\alpha = 15^o$, lat = 21.2^o, long = -63^o, k = 0.2

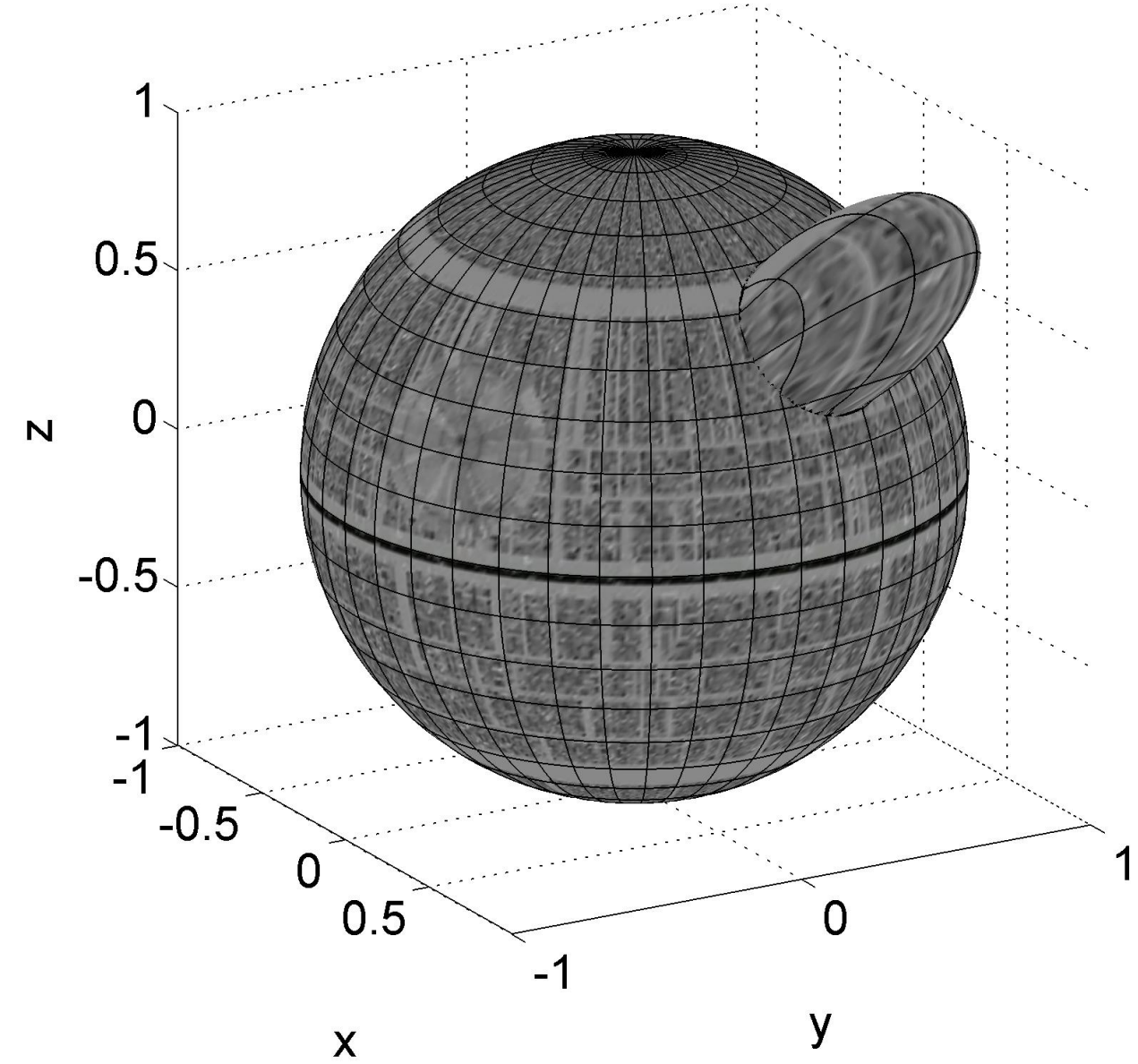
The *Death Star* from *Star Wars*(Diameter 120km)



Is the Force strong enough to give me a parabolic indent in my Death Star?

Don't forget to distort the lines of latitude and longitude too...

Death Star: α = 15°, lat = -219°, long = 195°, k = -0.75

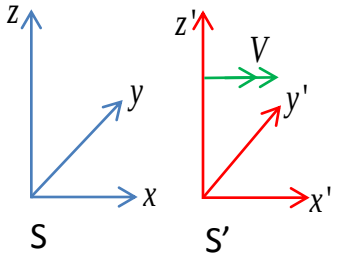


Give the Death Star a 'nose' if $k < 0$

Now that Disney has bought the rights to Star Wars...

Pinocchio has experienced the dark side of the Force ....

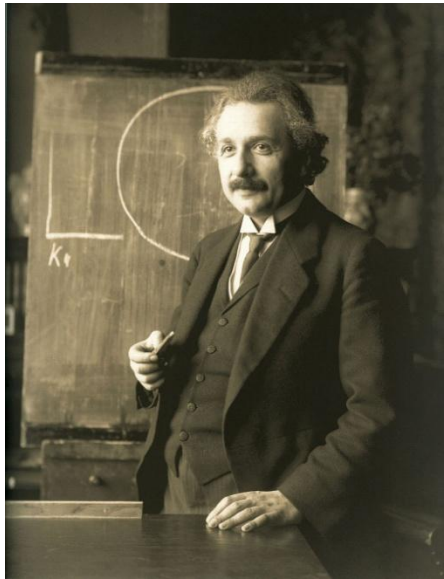
Licht ist keine Ente!



An Introduction to Special Relativity

$$\gamma = \left(1 - \frac{v^2}{c^2}\right)^{-\frac{1}{2}}$$

Licht ist kein Hamster!



Part 1

Light – the best understood physical phenomena ← Present day

Huygens, Fresnel, Young... – the **Wave model of light**

Electricity & **Magnetism** become **Electromagnetism**

➢*Foucault and Fizeau* use cunning clockwork to measure the speed of light

If light is a wave, what medium does it propagate in?

➢*Maxwell* predicts **Electromagnetic Waves**, with an **invariant speed** c

➢*Faraday, Helmholtz, Hertz, Lorentz* confirm *Maxwell* experimentally.

Michelson & Morely show that light can propagate in a vacuum

No "aether" is needed. **"Light is *not* a duck"***

{ Mostly 18th - 19th century

*A radiating hot duck in space will do just fine though. But a duck in a river is *not* a good model for 'ripples' of light

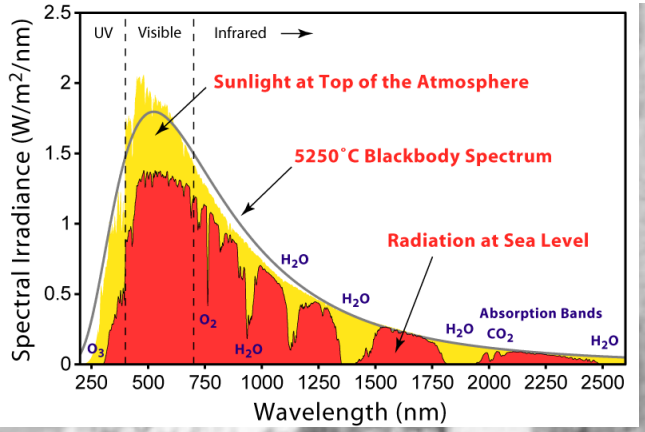
Galileo and Newton predict the motion of hamsters** between **frames of reference** in **relative motion**. **Is light like a beam of hamsters?**

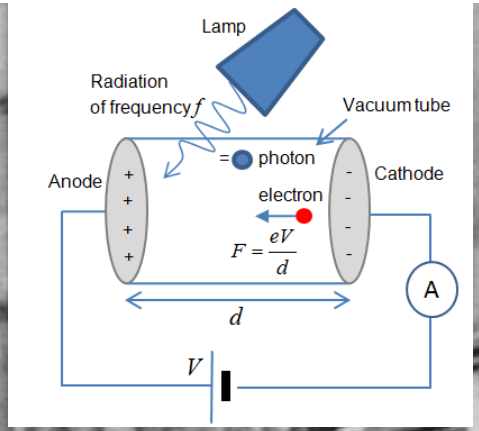
**No hamsters were actually hurled by these great Physicists

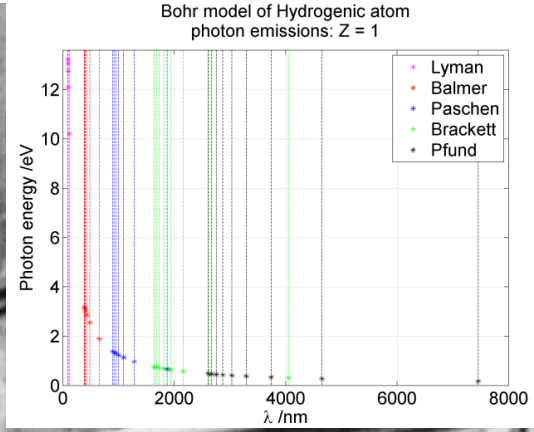
Einstein considers his reflection in a mirror if he were to travel at the speed of light. He concludes that **light is not like a beam of hamsters.** (Although with help from *Planck, Bohr* et al he will later conclude that you can divide the **energy** of light into discrete **quanta**)

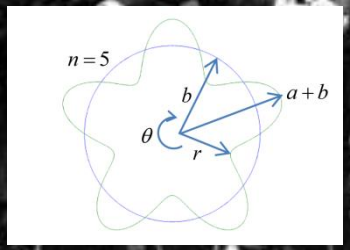
The *Feynman* **light clock** thought (Gedanken) experiment shows that **moving clocks run slow** in order to ensure the speed of light is constant in all frames of reference

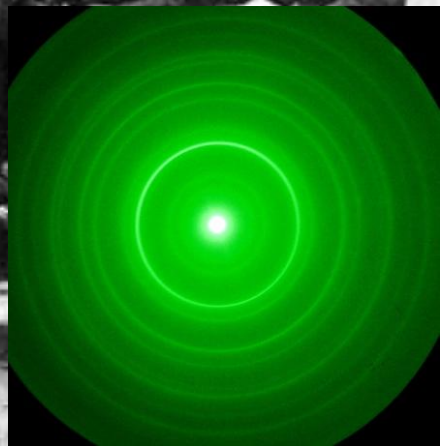
Experiments with **pions** show emitted **gamma rays** travel at the speed of light *regardless* of the speed of the pion which emits them







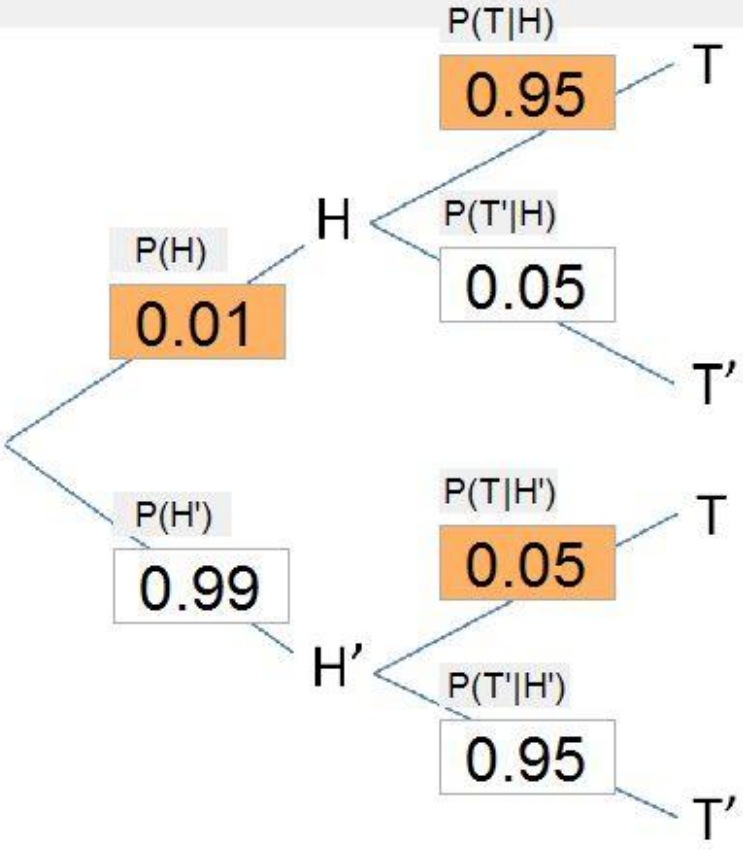


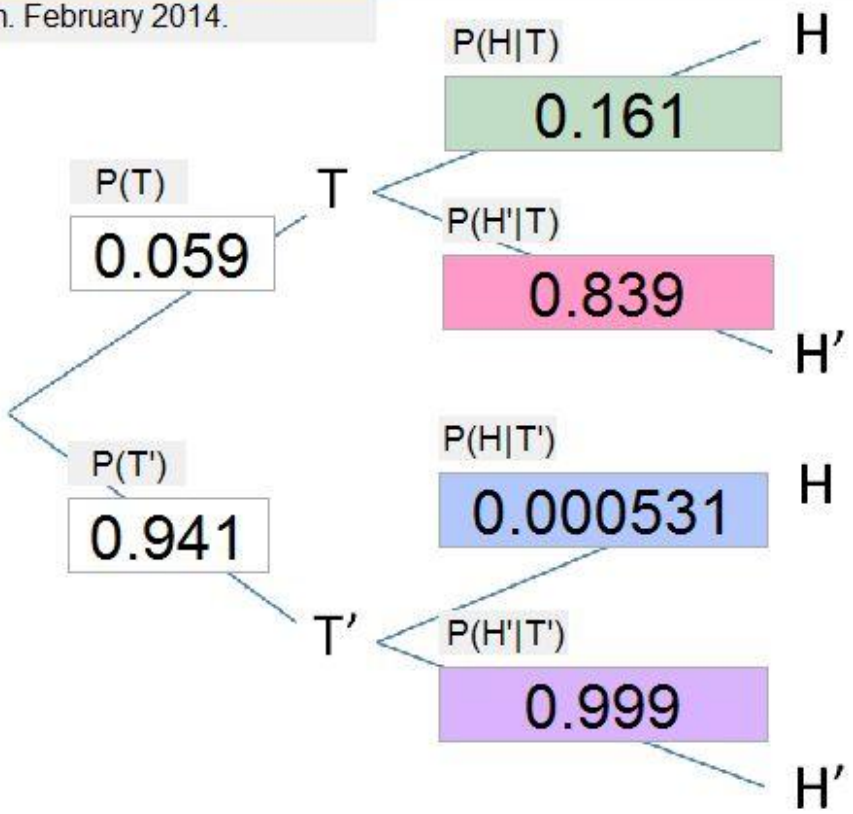


A history of Quantum Theory

BAYES-O-METER

A. French. February 2014.





P(H|T)
Probability of hypothesis true given pass of test

0.161

P(H'|T) (False positive)
Probability of hypothesis false given pass of test

0.839

P(H|T') (False negative)
Probability of hypothesis true given fail of test

0.000531

P(H'|T')
Probability of hypothesis false given fail of test

0.999

Thomas Bayes
1701-1761

The logistic map and population modelling

I published this model in 1976

Robert May
1936-

Assume an ecosystem can support a maximum number of rabbits.
Let x be the fraction of this maximum at year n.

To account for **reproduction**, next year's population is proportional to the previous.

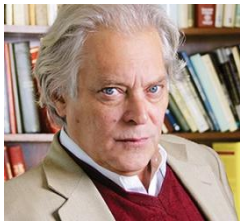
To account for **starvation**, next year's population is *also proportional* to the fraction of the maximum population as yet unfilled.

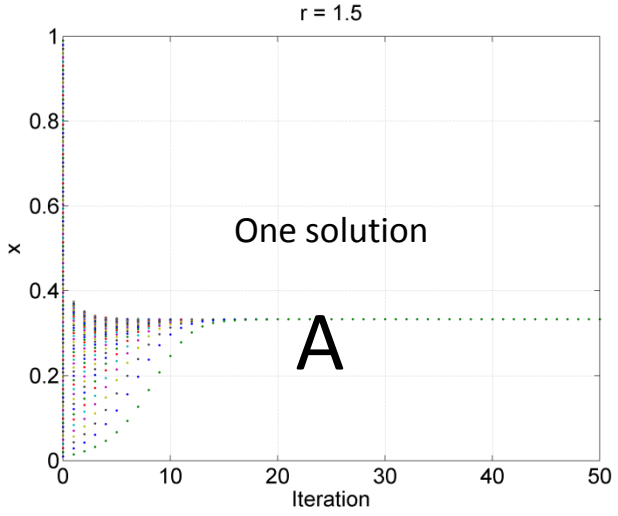
$$x_{n+1} = rx_n\left(1 - x_n\right)$$

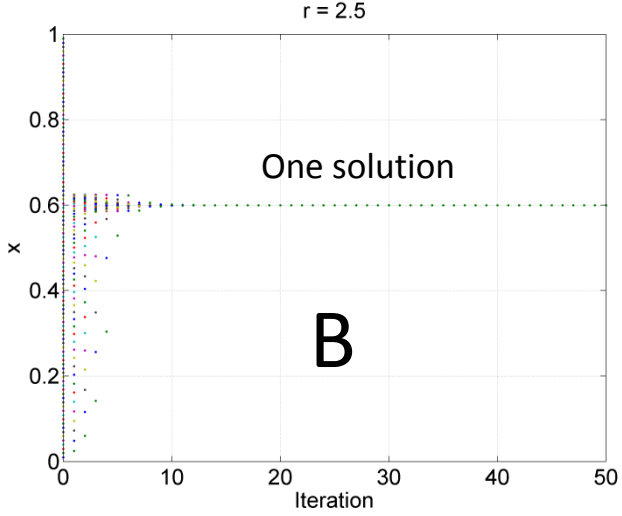
Growth parameter

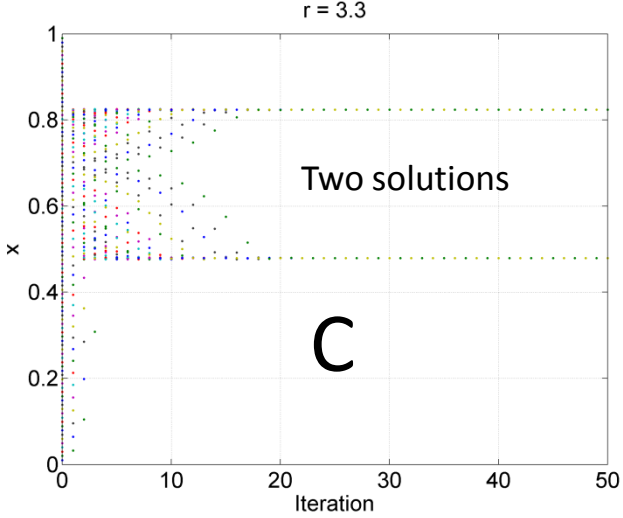
The population next year is predicted using this **iterative equation** called a **logistic map**

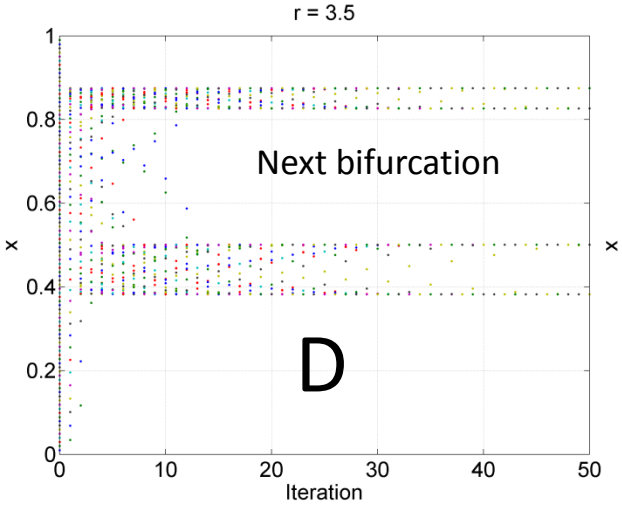
The pattern of x values with n is not always simple .....

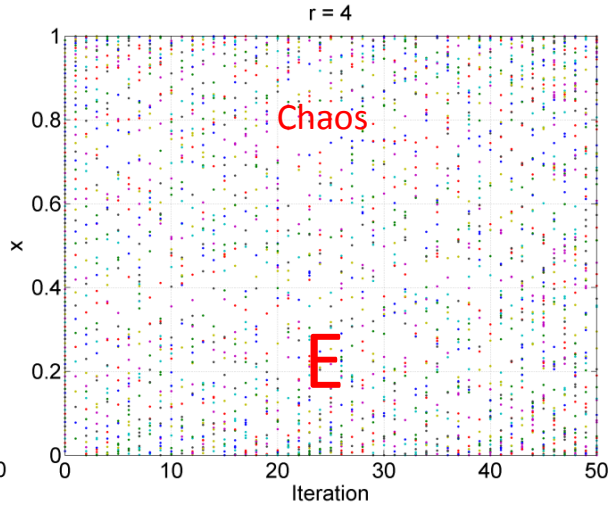




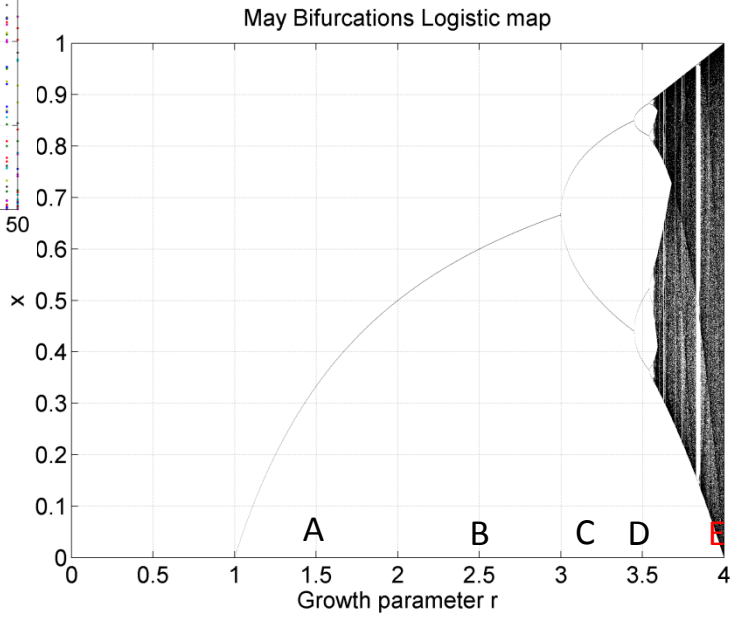








$$x_{n+1} = r x_n \left(1 - x_n\right)$$



Tracking the bifurcations maps the 'road to chaos'. The ratio of successive bifurcation intervals is a **universal constant!**

4.669201609…

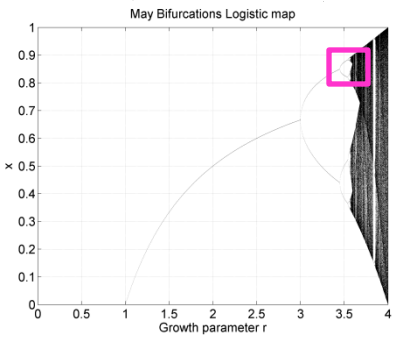
May Bifurcations Logistic map

It turns out the ratio of successive bifurcation intervals is a **universal constant!**

4.669201609…

$$x_{n+1} = r x_n \left(1 - x_n\right)$$

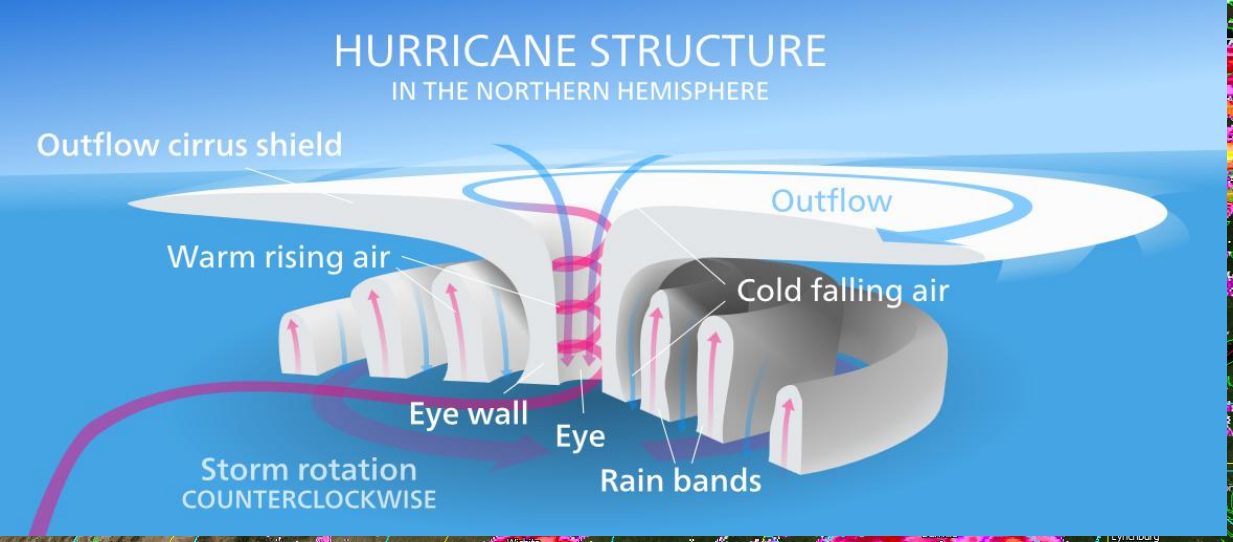
Zooming in reveals an ‘infinite tree of bifurcations’ during chaotic regions



0.9
0.895
0.89
x 0.885
0.88
0.875
0.87

3.54 3.56 3.58 3.6 3.62 3.64 3.66

Growth parameter r

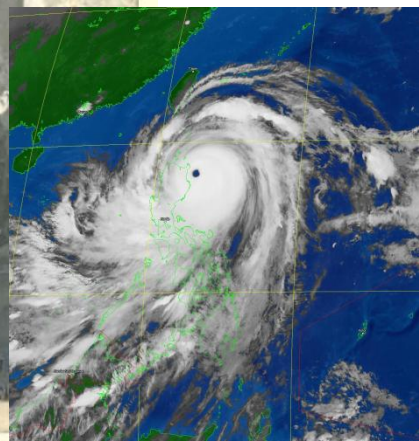


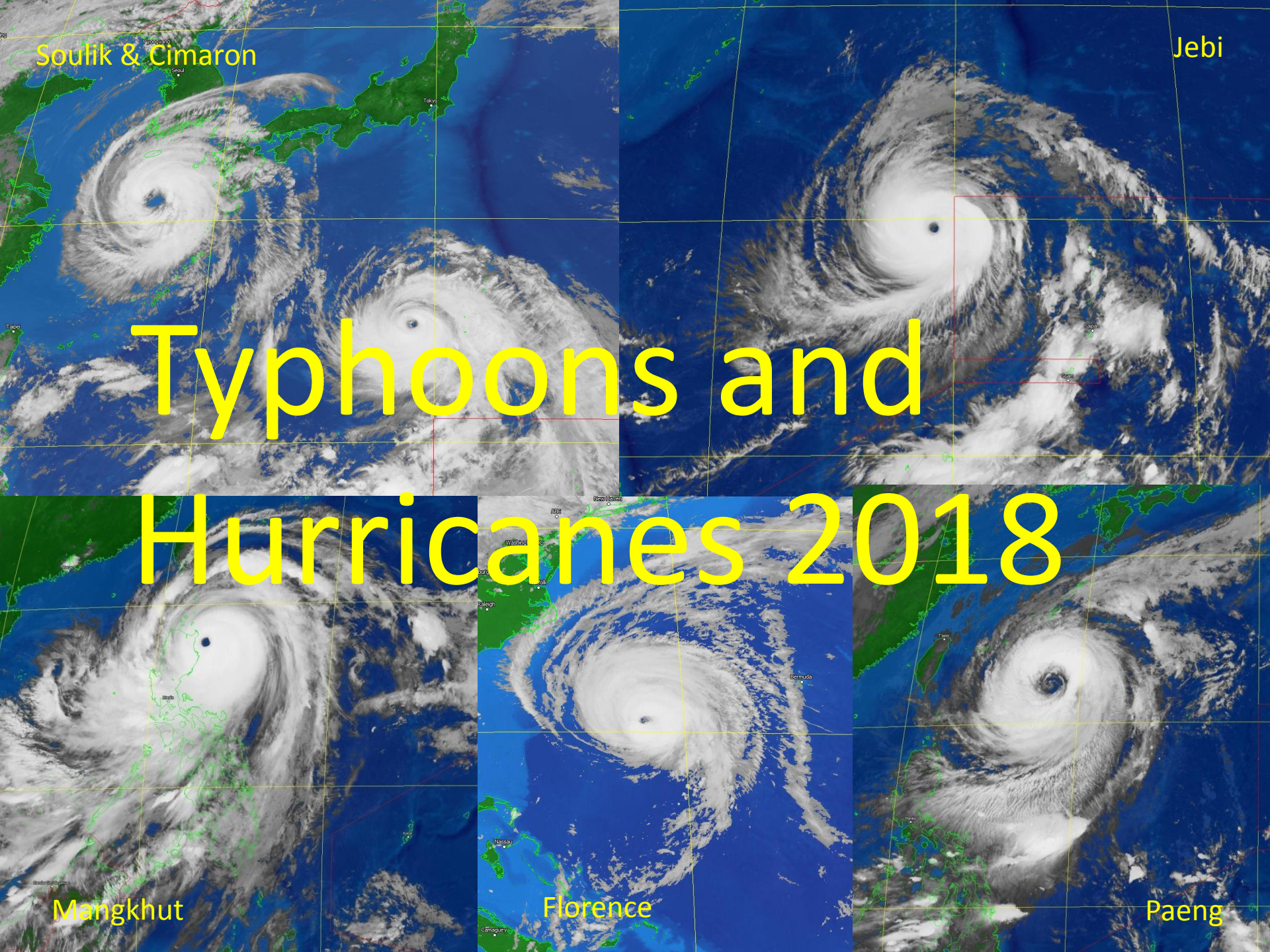
$$r = ae^{b\theta}$$

Context & Meaning

College, 1937

Sir James Lighthill
1924-1988




Soulik & Cimaron
Jebi
Typhoons and
Hurricanes 2018
Mangkhut
Florence
Paeng

Some concluding thoughts

Stories are a natural way of packaging ideas, making the associated methods/lessons etc *memorable*, *relatable* and *contextualized*

Most students will find it tough to engage with an idea that is not placed in the context of their previous experience

Stories interlink ideas into a tangible, and hopefully coherent, whole. They are necessarily cross-curricular.

New ideas are incorporated when the narrative demands it. This is good motivation for learning. Nobody reads a textbook cover to cover, but you can happily devour *The Hobbit/Sense & Sensibility/Bring up the Bodies*/Ulysses*** in a day.

*Well maybe two ** !