School of Mathematics
FACULTY OF MATHEMATICAL AND PHYSICAL SCIENCES
UNIVERSITY OF LEEDS

HOW TO GO FROM SAVING THE WORLD FROM GLOBAL WARMING TO PREDICTING THE FUTURE OF OUR SUN IN 5 BILLION YEARS!

Dr Chris Wareing

13th November 2012

THE CLIMATE IS CHANGING.

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WHO BELIEVES IN GLOBAL WARMING?

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WHO THINKS MANKIND IS DRIVING THIS WARMING?

Carbon Dioxide (CO_2) is a greenhouse gas. Emitters include:

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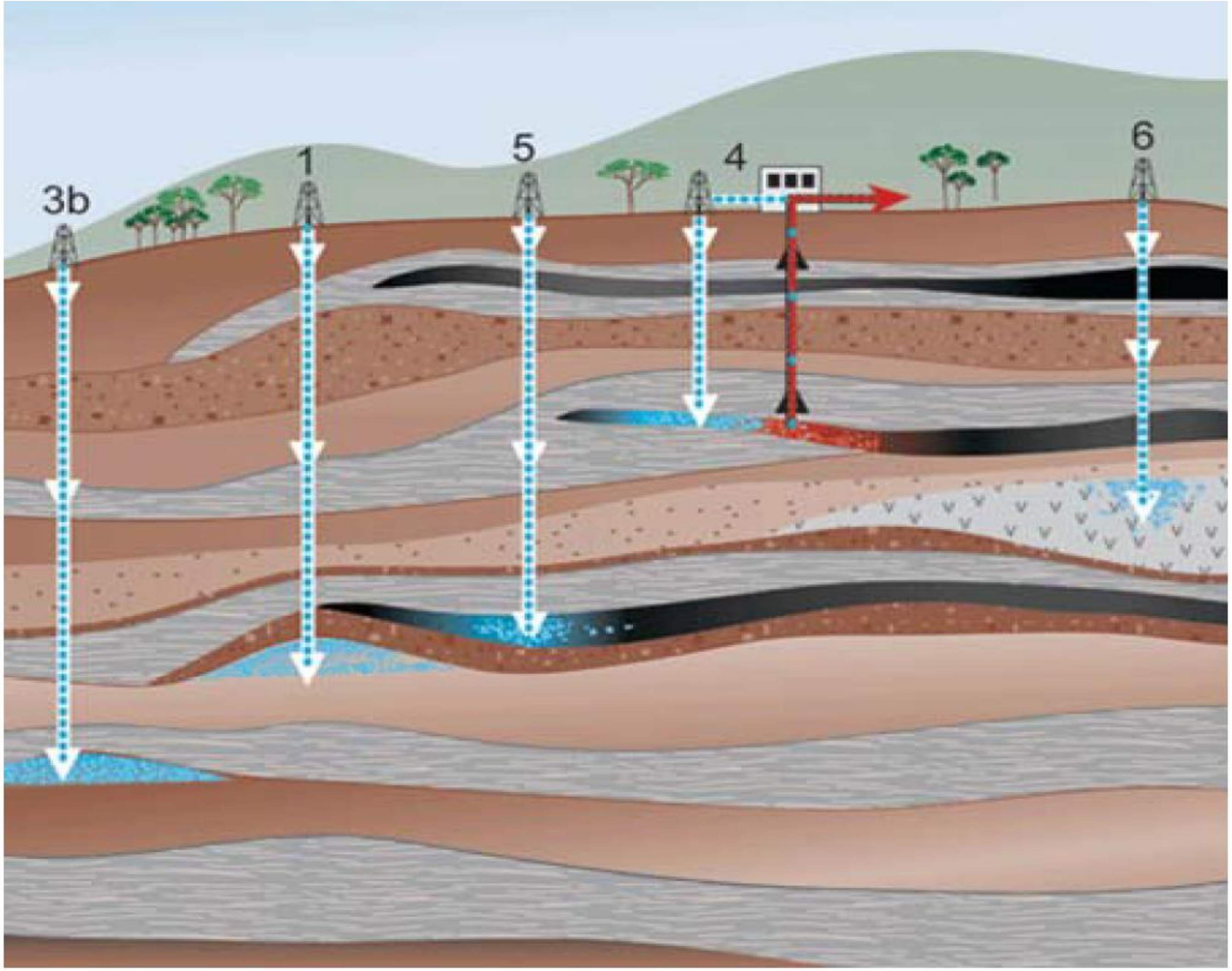
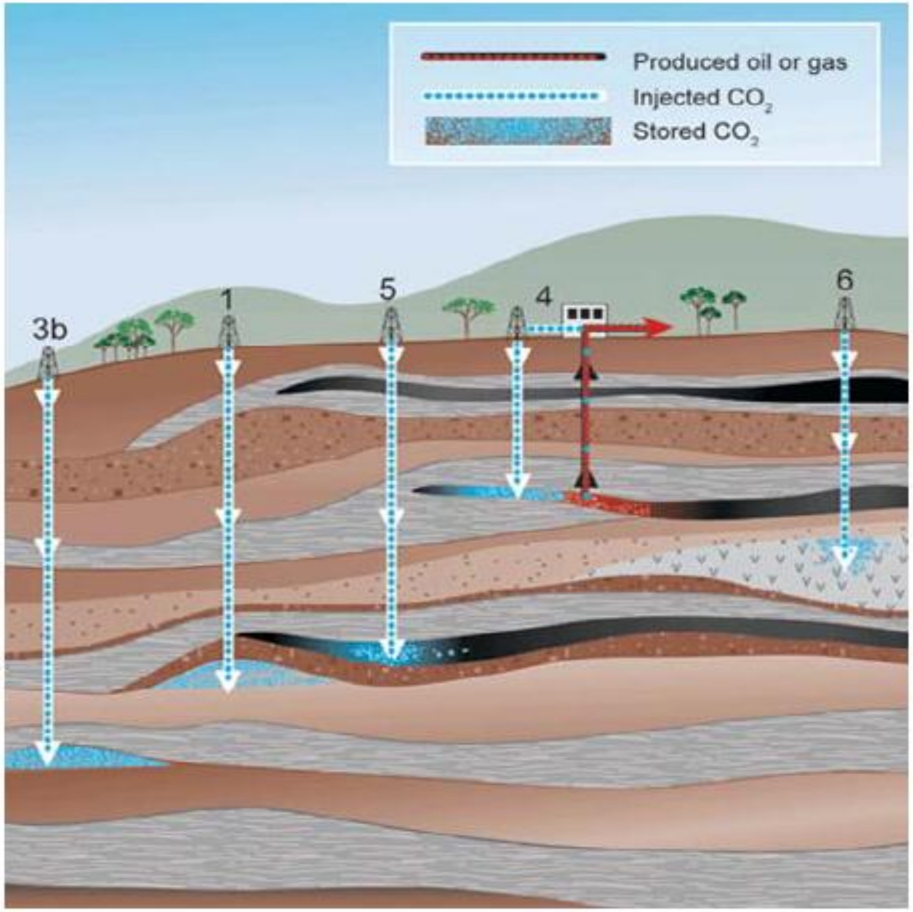
50% power / 50% cars & individuals

Where could we store the CO_2 once we've captured it?



Exhausted oil reserves

But, how do we get it there?



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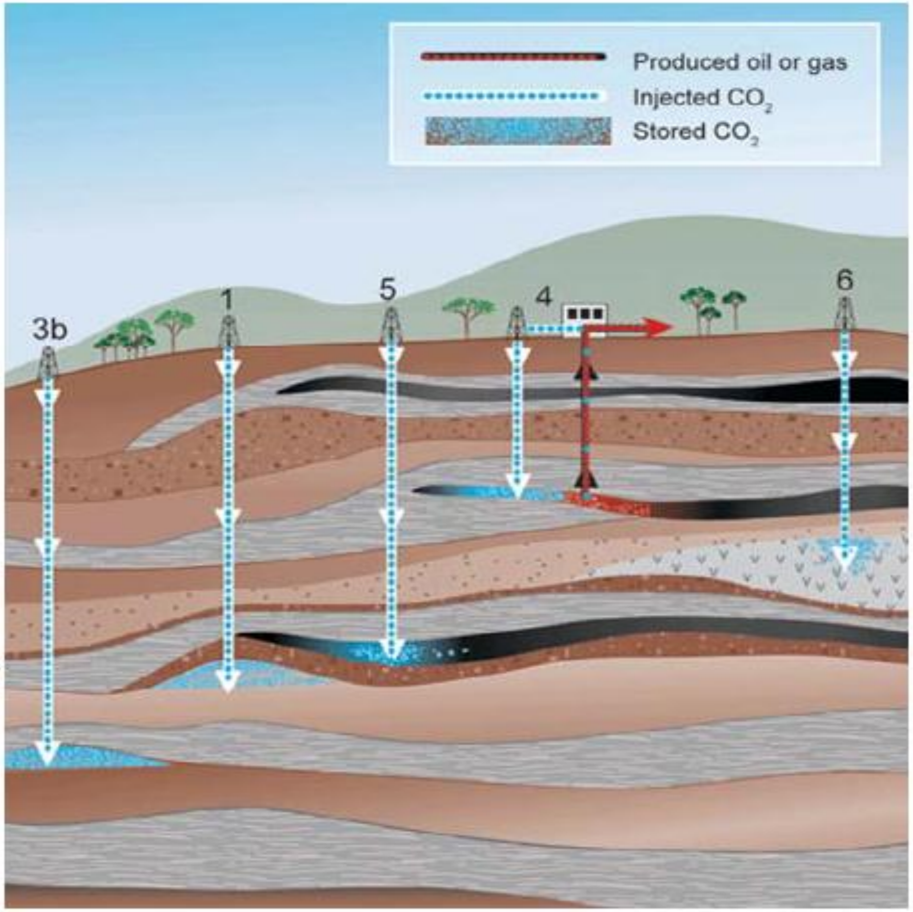


JCB

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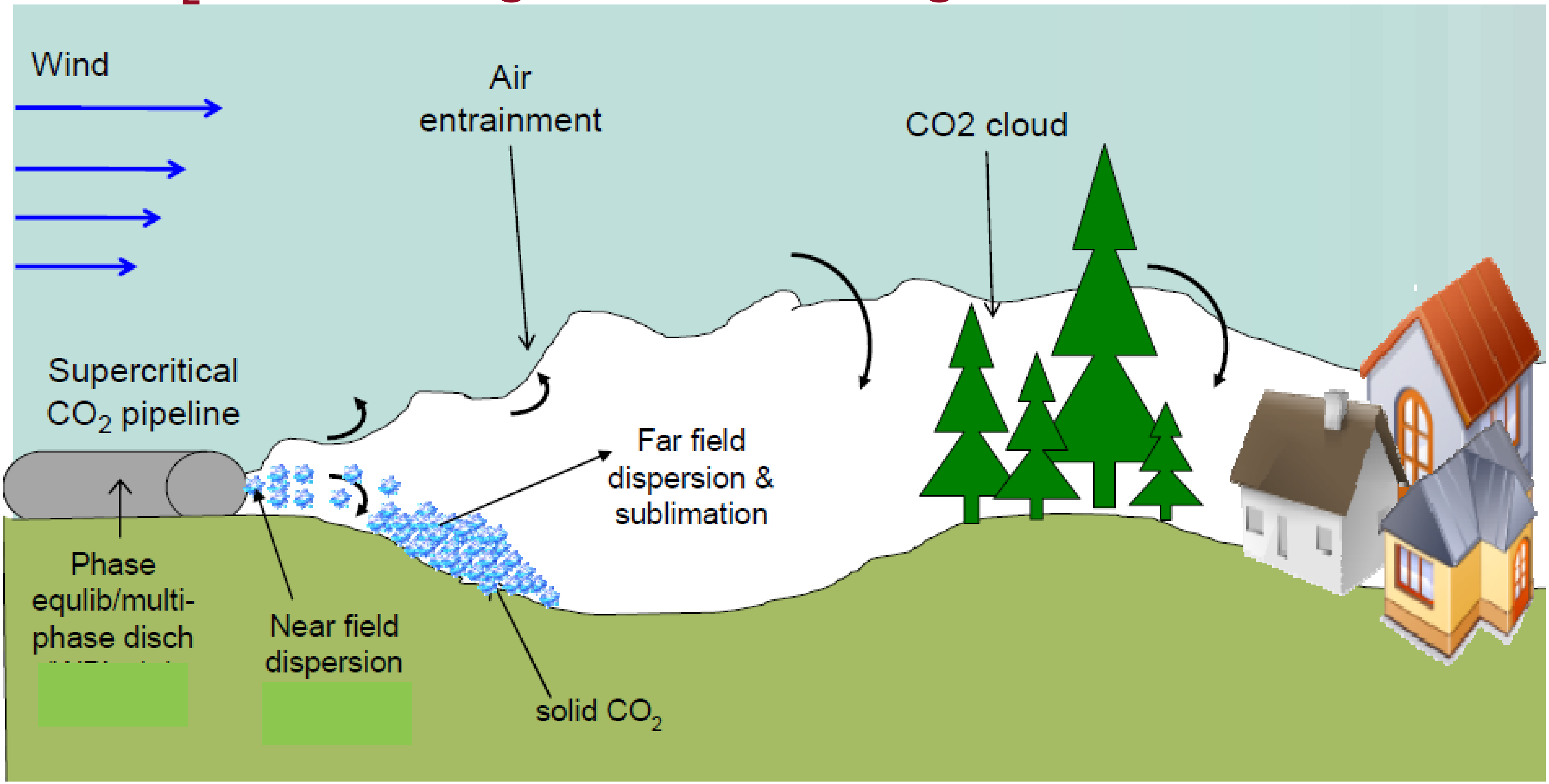
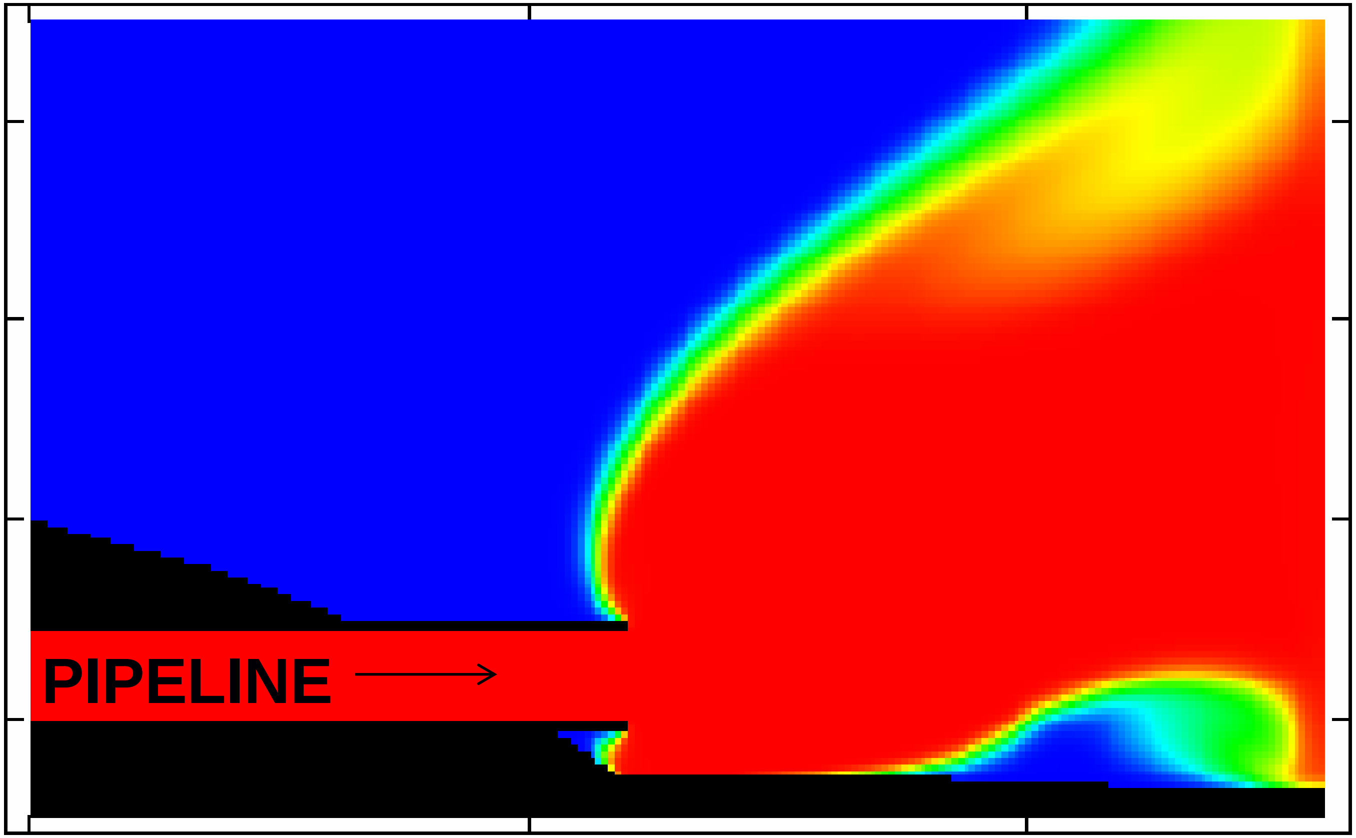
Carlsbad Natural Gas pipeline explosion, New Mexico, 19 Aug 2000

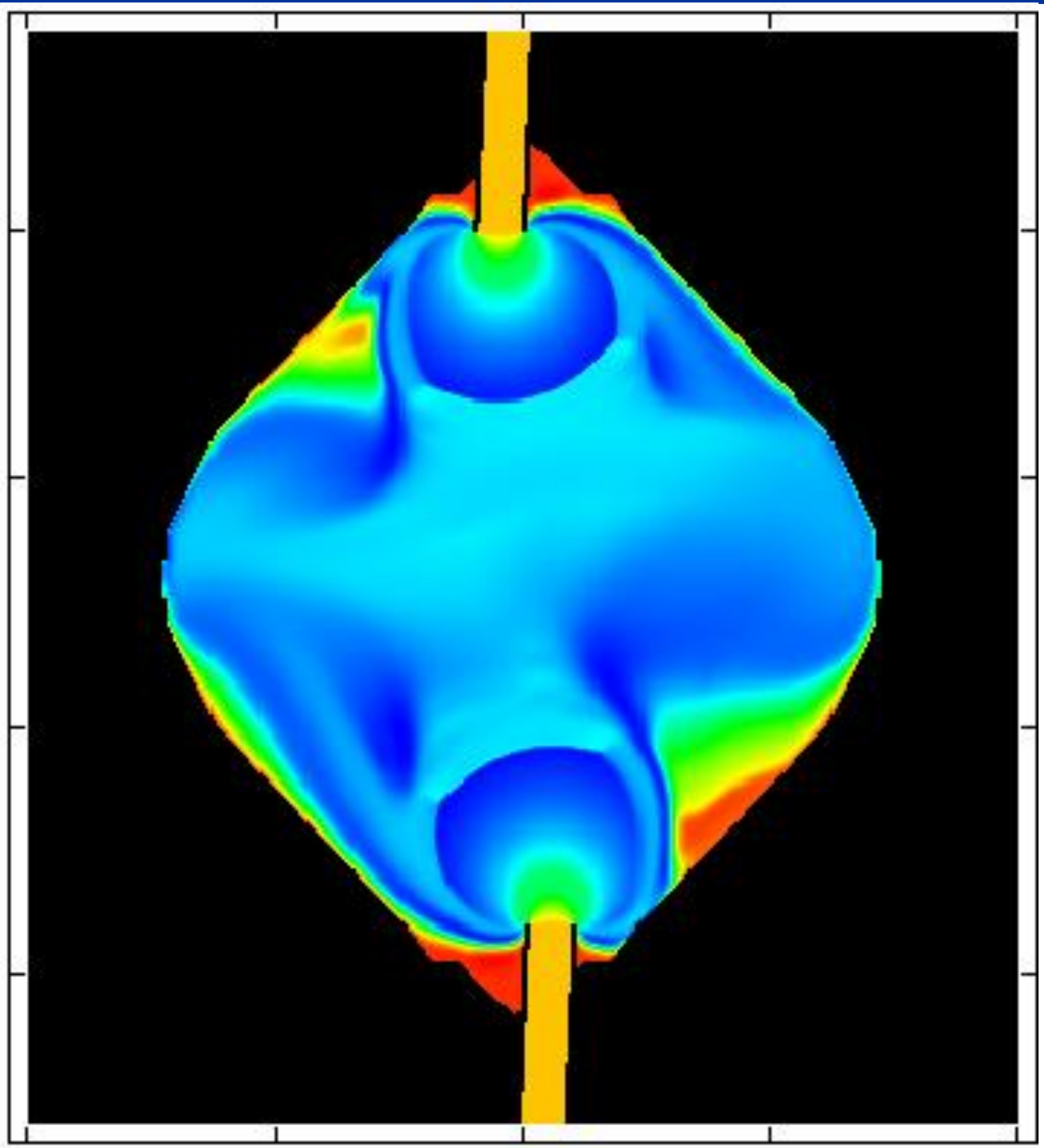
A CO_2 leak won’t ignite like natural gas



Obviously you can't do many experiments with this, so we simulate models

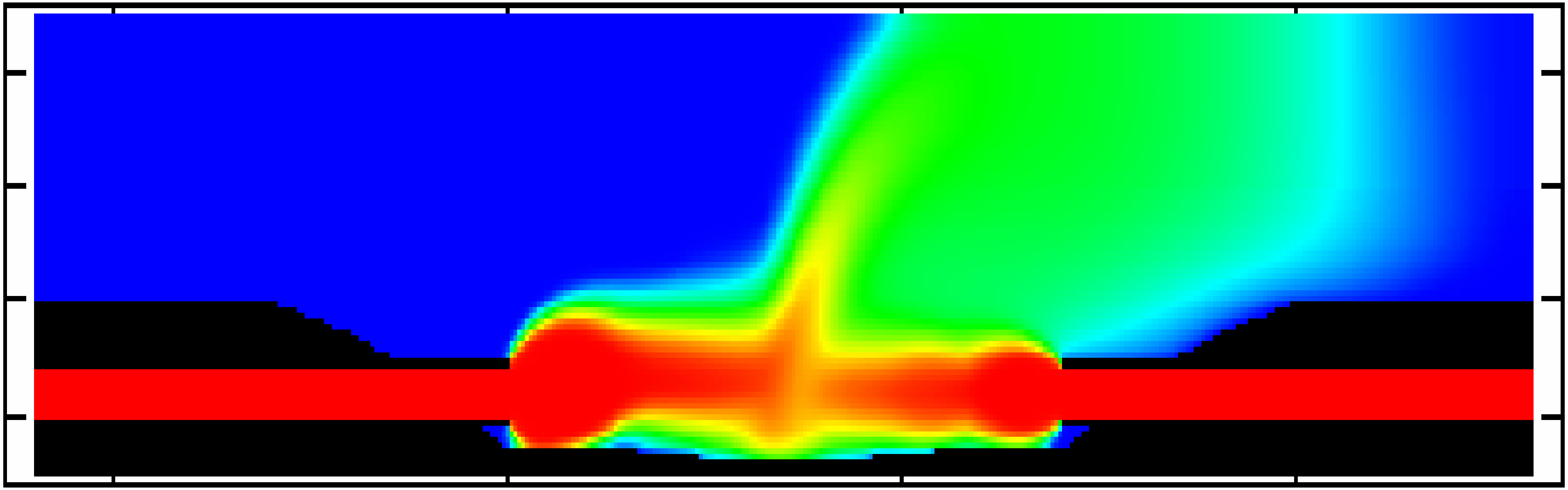


Here's an example of a ruptured pipeline in a crater...



Crater view
from the top down

Misaligned pipelines, following a catastrophic rupture



Side view of a crater and flow of CO_2 out of the crater

How do we ‘simulate’ flows like this?

Use the equations of fluid flow...

Conservation equations...

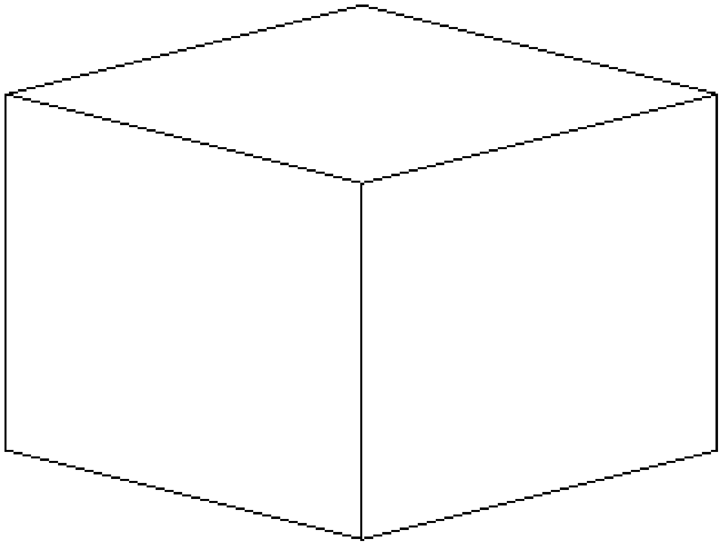
$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \mathbf{u}) = 0 \quad \text{equation of continuity,}$$

$$\frac{\partial \rho C}{\partial t} + \nabla \cdot (\rho C \mathbf{u}) = 0 \quad \text{scalar transport,}$$

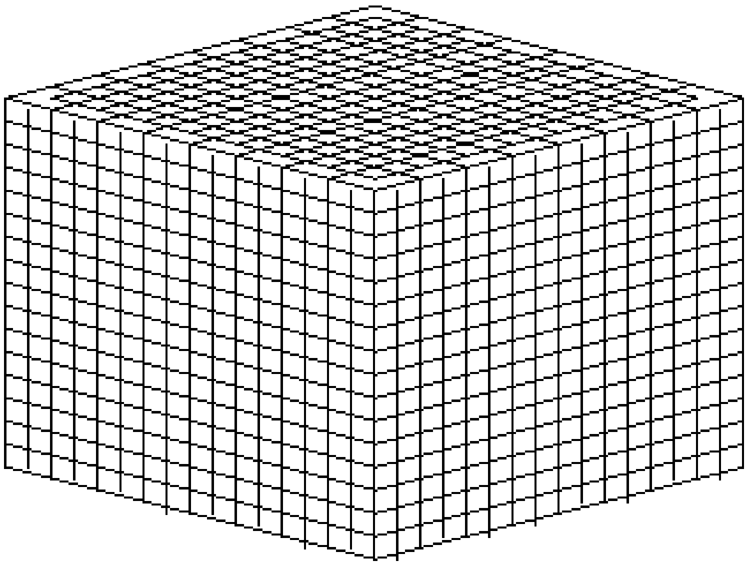
$$\frac{\partial \rho \mathbf{u}}{\partial t} + \rho(\mathbf{u} \cdot \nabla)\mathbf{u} + \nabla p = 0 \quad \text{momentum,}$$

$$\frac{\partial e}{\partial t} + \nabla \cdot [\mathbf{u}(e + p)] = 0 \quad \text{energy,}$$

Take a domain e.g. a simple box...



...and divide it up into a number of cells



Take the conditions (pressure, density, velocity) in each cell and then solve these equations between the cells

CLAY INSTITUTE PRIZES

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June 24th 2000

- **Seven Millennium Prize problems, chosen by leading experts worldwide**
- **Classical problems that have resisted solution for years**
- **One has been awarded, for resolution of the Poincare Conjecture**
- **Another is for a solution of, or considerable progress towards the understanding of, the Navier-Stokes equations of fluid flow**

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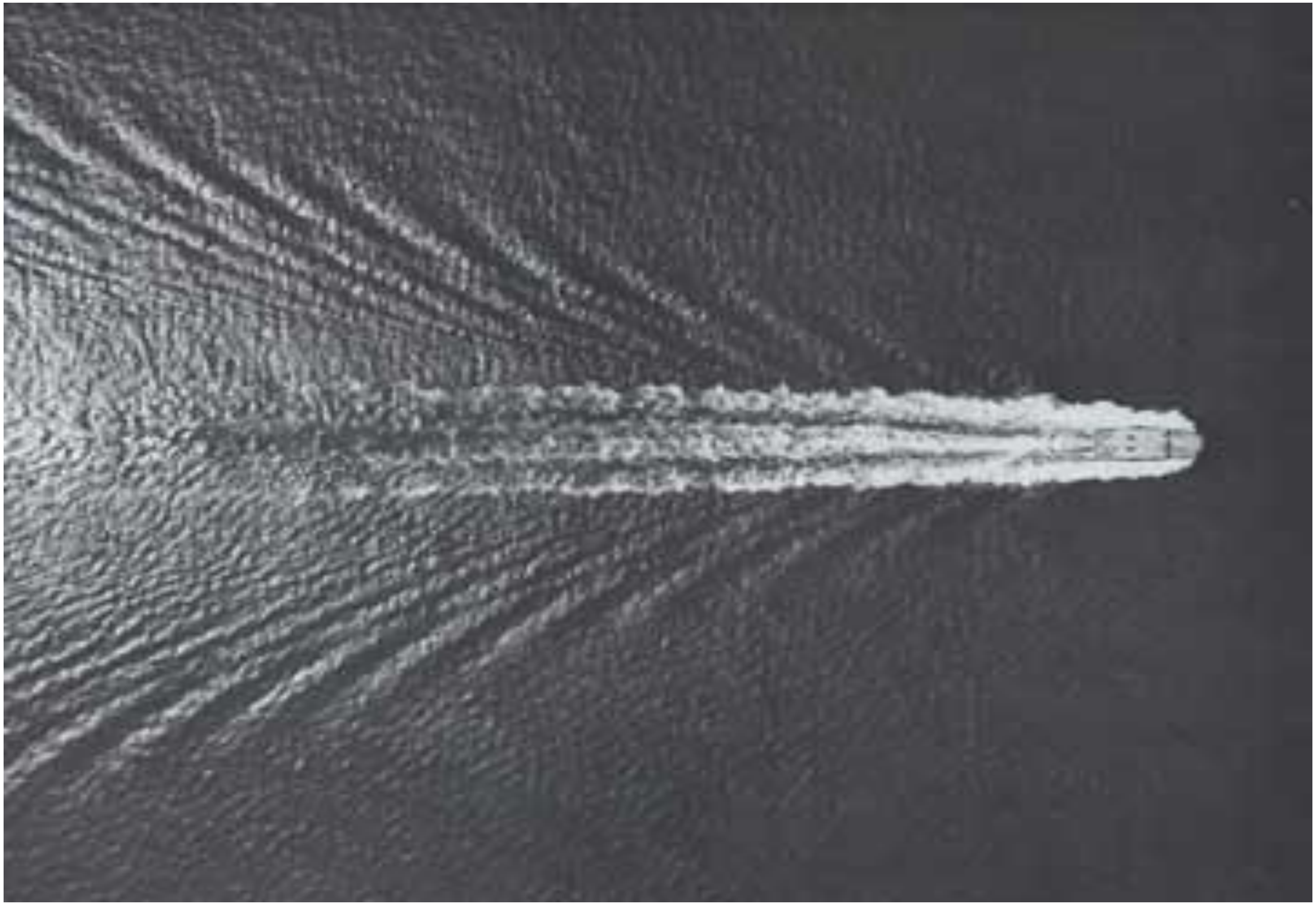
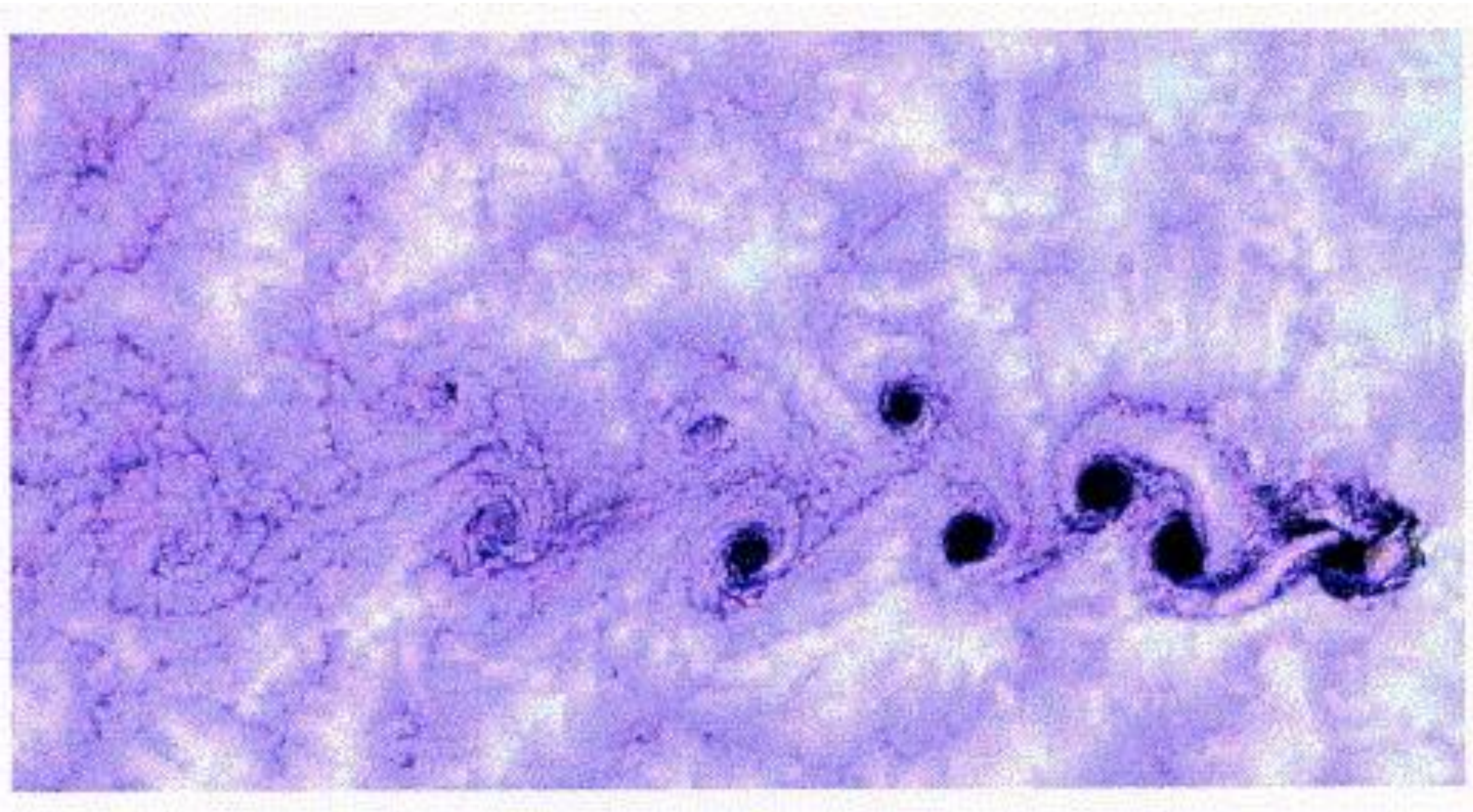
$ 1,000,000

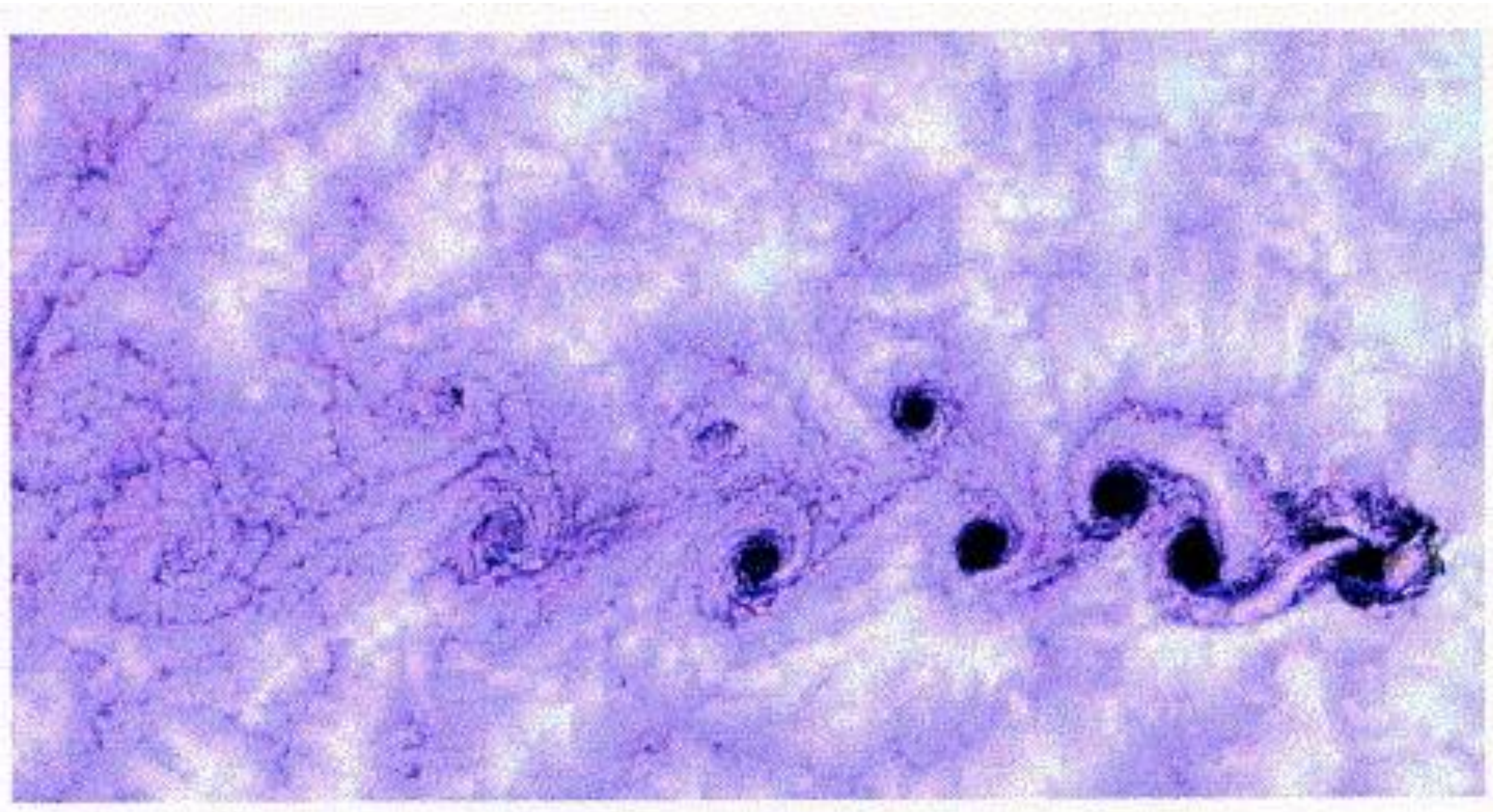
Wider applications of fluid flow equations:-

- **Waves follow a boat as it meanders across the lake**
- **Turbulent air currents follow our flight in a modern jet**
- **Mathematicians and physicists believe that an explanation for and the prediction of both the breeze and the turbulence can be found through an understanding of solutions to the Navier-Stokes equations**
- **Although these equations were written down in the 19th Century, our understanding of them remains minimal**
- **The challenge is to make substantial progress toward a mathematical theory which will unlock the secrets hidden in the Navier-Stokes equations**

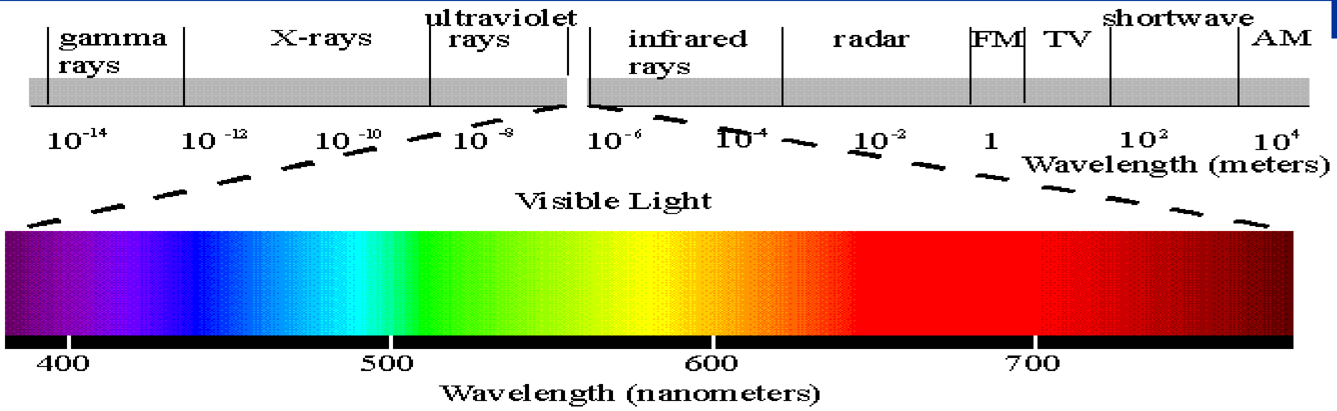


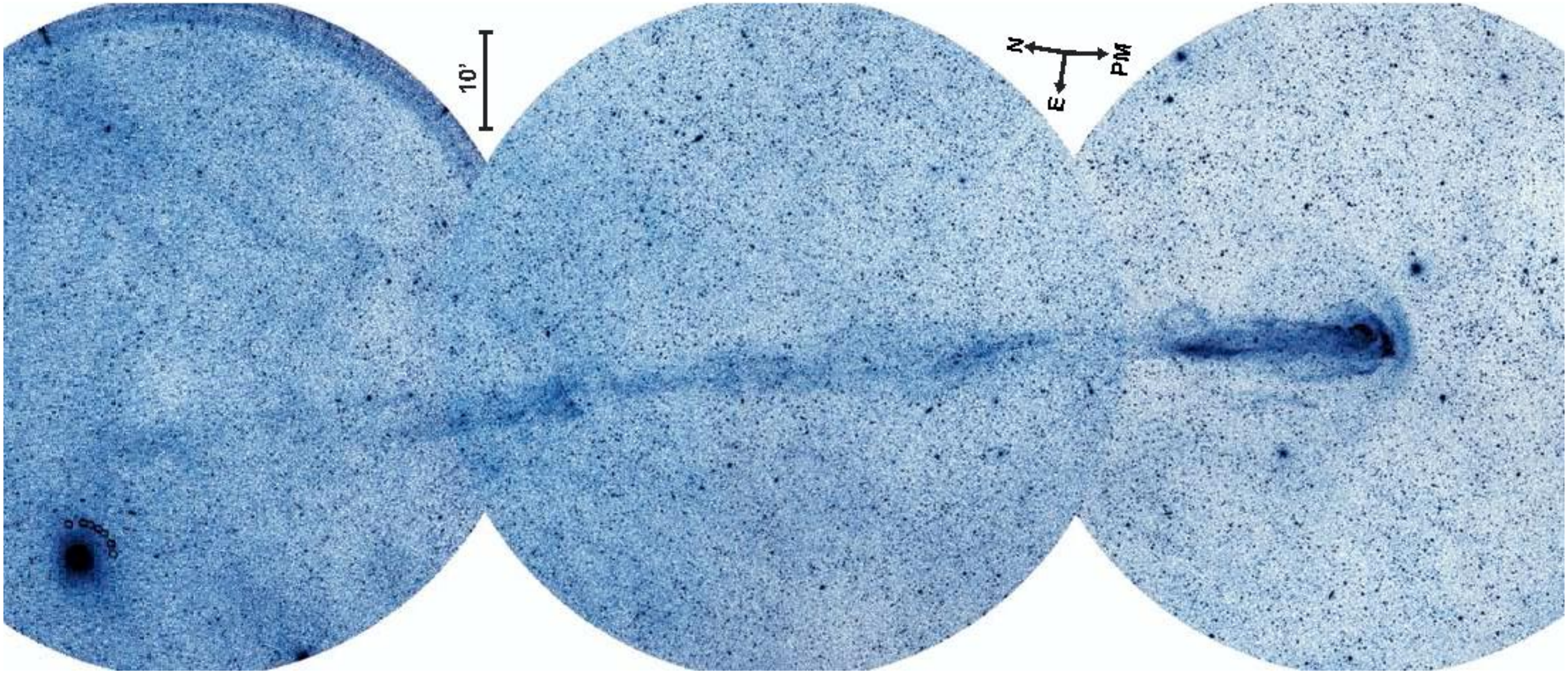
Wave pattern behind a ship, photographed from above





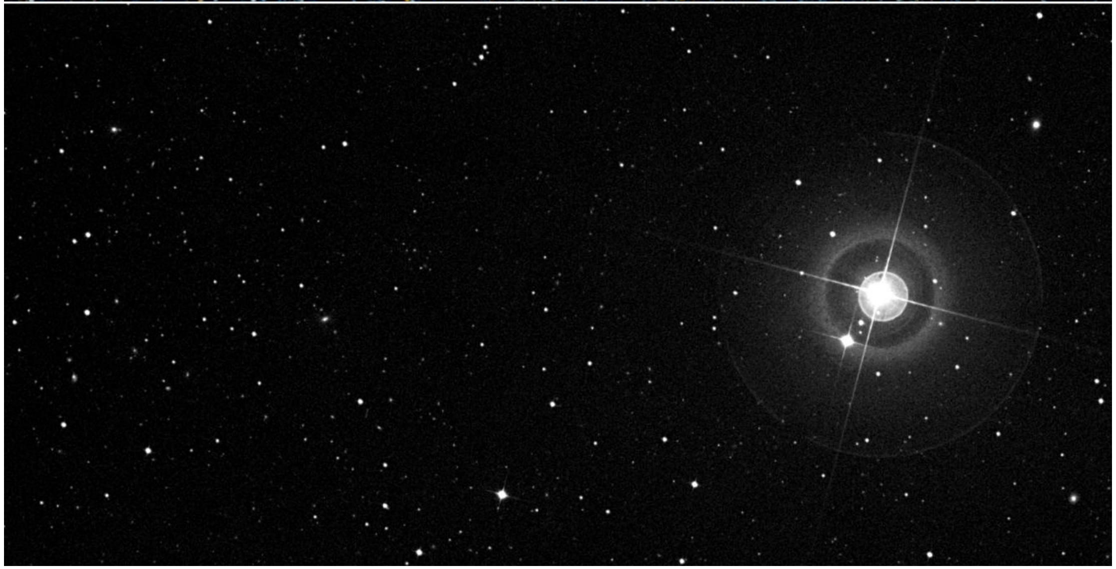
Atmospheric flow past an island in the South Pacific


gamma rays
X-rays
ultraviolet rays
infrared rays
radar
FM
TV
shortwave
AM
10^{-14} 10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 1 10^{2} 10^{4}
Wavelength (meters)
Visible Light
400 500 600 700
Wavelength (nanometers)


10'
N
PM
E

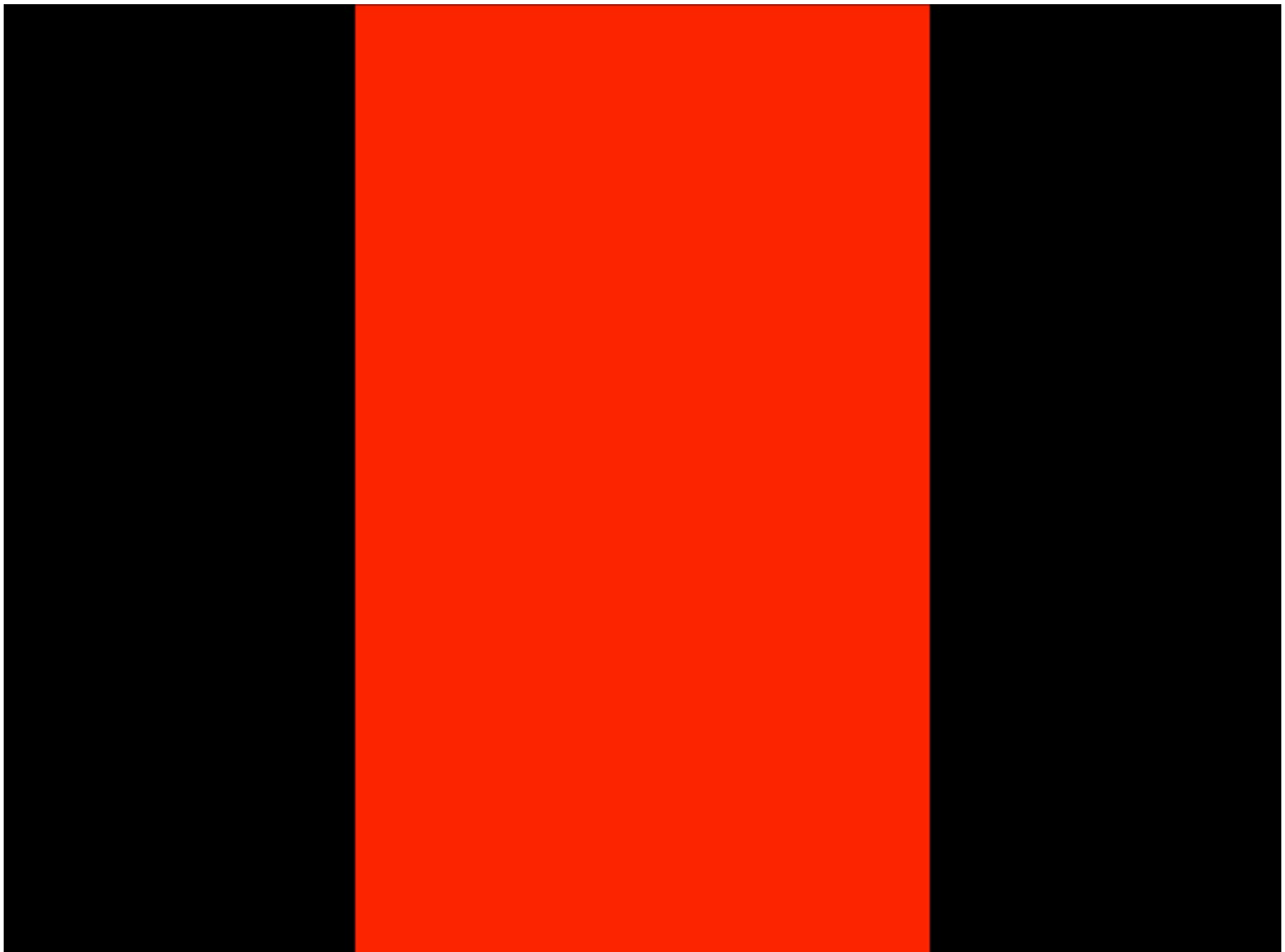
Nasa artistic video impression...

Ultra-violet



Visible light

Lets make the density very low... And the size scale very big...



Of course to calculate flows like these, you need to perform many, many calculations in many, many cells over very large grids!

You could do it by hand (for a very long time!).

Or...

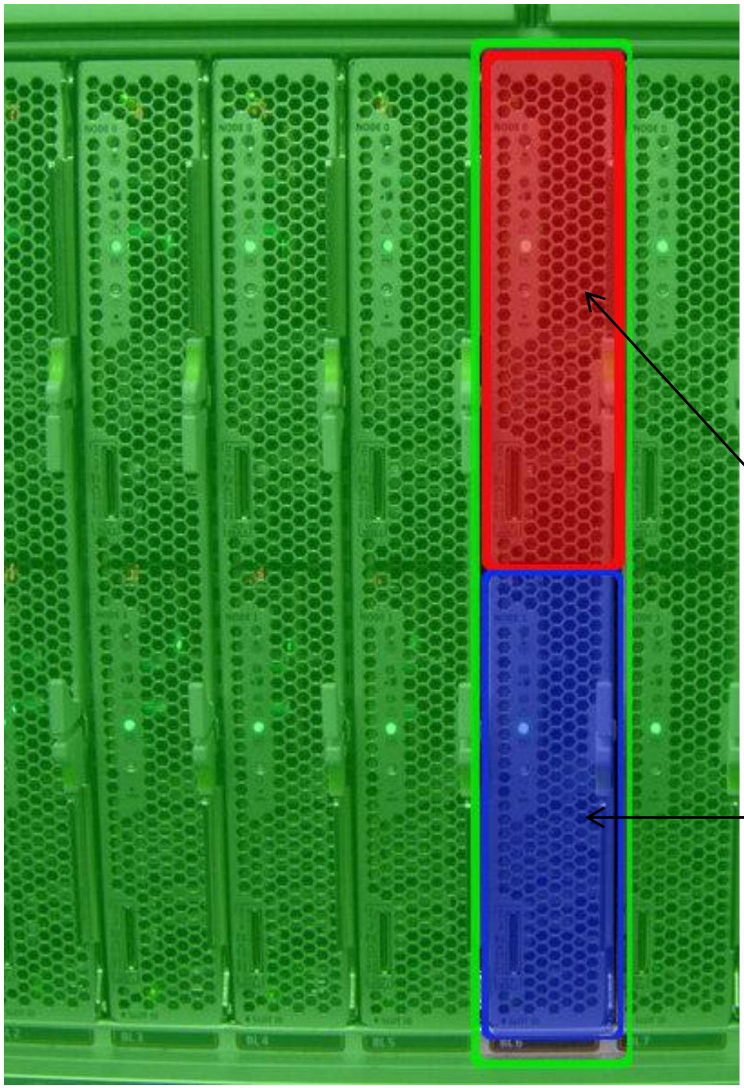
Use a computer, but not a normal computer...

=

2 Desktop PCs

1 Blade

No monitor, no keyboard or mouse, saves space!



Build up these blades...

One blade contains the equivalent of two desktop PCs, each multi-core with 12 cores.

A total of 24 processing cores

...into shelves and bookcases...

1 *shelf* = 12 blades = 288 cores

1 *chassis* = 4 shelves = 48 blades = 1152 cores

...to build a supercomputer!

If each of the three grey chassis on show here were full = 3456 cores

How powerful is this machine?

Each core has a speed of 2.66GHz – that means it can perform 2,660,000,000 floating point operations per second (FLOPS).

So, this computer is capable of 3456 x 2,660,000,000 = 9.1 TeraFLOPS

The fastest computer in the world is 2000 times faster – it's built by IBM, has 1.5 million cores and can reach 20,132.7 TeraFLOPS

Compared to the world's first computer – the small-scale experimental machine, known as SSEM or 'the Baby', built at the University of Manchester. This machine was built by Alan Turing amongst others.

Ran it's first program on June 21st 1948 and had all the components classically regarded as characteristic of the basic computer. Baby took around 1.2milliseconds per instruction, or 833 instructions per second

Computing is now 24,000,000 times quicker!

One of my simulations takes 6 hours on 60 cores of the supercomputer.

It would take 360 hours, or 15 days on one computer!

Of course if you decided to do all this yourself with a calculator, lets say you could do 5 calculations a second. That's 2.66GHz/5 times slower than the computer.

So, it'd take you 15 x 2,660,000,000 / 5, or 21.9 million years...

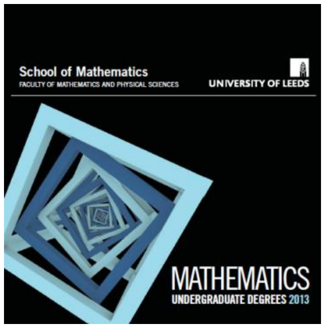
Computers are handy then, but for these kind of simulations, the computer only ever does what you tell it – it's up the mathematician to decide whether the results are any good!

And you need to know what you're doing!

What do you do if you want to have a crack at the Clay Institute Millenium Prize?

Or maybe you want to use computers not just for word processing and writing presentations like this, but instead to develop new ways to change the world, like mitigating climate change?

Continue your studies with Mathematics as a degree...
(or Engineering, or Physics, or even Astrophysics as I did!)



Degrees at the University of Leeds

Single Honours Mathematics degrees	Joint Honours parented by Mathematics	Joint Honours parented by others
MMath/BSc Mathematics	BSc Biology & Maths	BSc French/German & Maths
BSc Actuarial Maths	BSc Economics & Maths	BSc Maths & Philosophy
BSc Maths with Finance	BSc Geography & Maths	BSc Chemistry & Maths
BSc Mathematical Studies	BSc Management & Maths	BSc Physics & Maths
BSc Maths and Statistics	BSc Maths & Music	MNatSci Natural Sciences

MMath/BSc Mathematics

Our most popular degree

Available as a **3 year BSc Bachelors degree** **or a** **4 year MMath, BSc Integrated Masters degree**

Up to **one sixth** of your study (20 credits each year) can be **Elective Modules** from across the University

The **Core** takes up Year 1 and about half of Year 2

Then you **Specialise,** with many options available across all of mathematics

Typical Conditional Offer

For Single Honours degrees

Mathematics / Maths with Finance / Actuarial Maths / Mathematical Studies / Maths & Stats

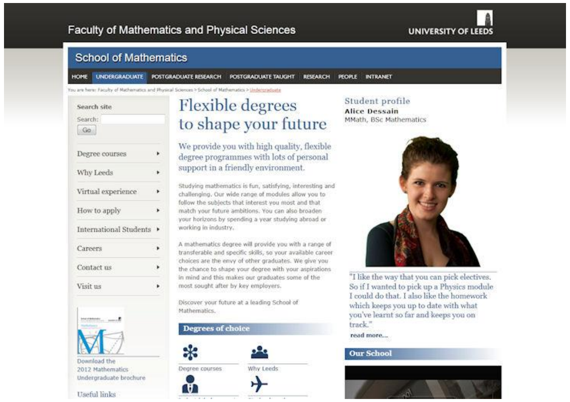
- **A*AB or AAA**, *or*
- **A*BB or A*AC or AAB** with **Further Mathematics**, *or*
- **A*BB or A*AC or AAB** PLUS **A** in AS-level **Further Maths**

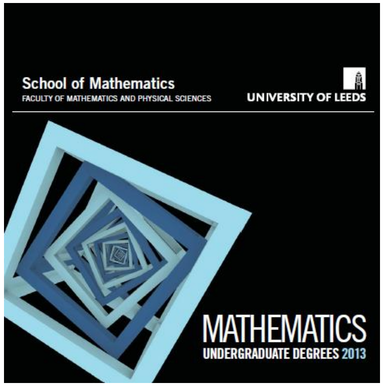
The first grade quoted is in **Mathematics**

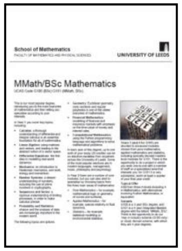
- We welcome applications from people with **other qualifications** - please ask about our requirements
- We normally allow **General Studies** or **Critical Thinking** as one of the three A-levels
- You must meet the **matriculation requirements** of a pass in five subjects at GCSE level or above, including English at grade C or above, or equivalent.
- For **Joint Honours degrees** see our website, leaflets or brochure

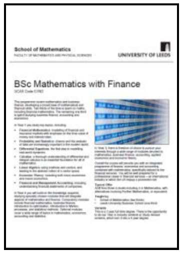
More Information

- **www.maths.leeds.ac.uk**
  Information, videos, profiles, careers
- **Mathematics Undergraduate Brochure**
  Covers all degrees we parent
- **Leaflets**
  One for each degree we parent
- **maths.admiss@leeds.ac.uk**
  Any questions!





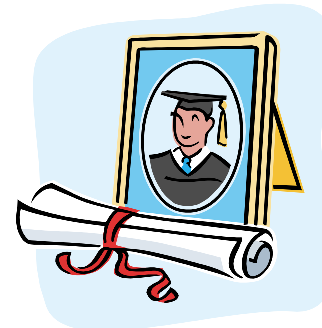




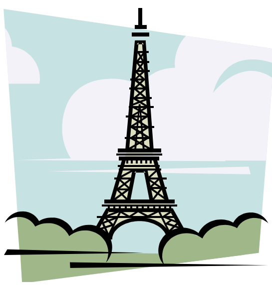
Thanks for listening!

Any questions?

Flexible Degrees



- Elective modules
  On some degrees you can take modules from across the University. Popular choices are in modern languages, management, music, philosophy and psychology



- Study Abroad scheme
  Spend Year 3 abroad and Year 4 back in Leeds
  Many partner institutions in Europe and North America
  Available with all degrees we parent

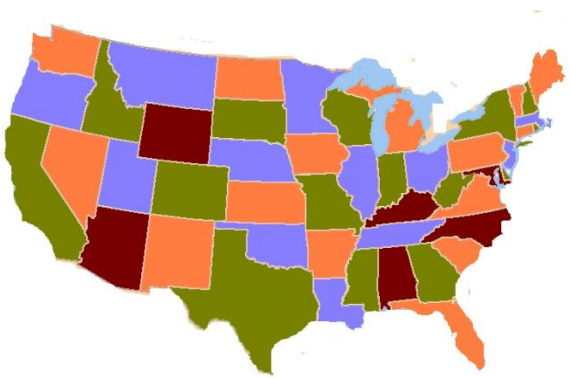
- Year in Industry scheme
  Spend Year 3 working and Year 4 back at university
  Available with all BSc degrees we parent

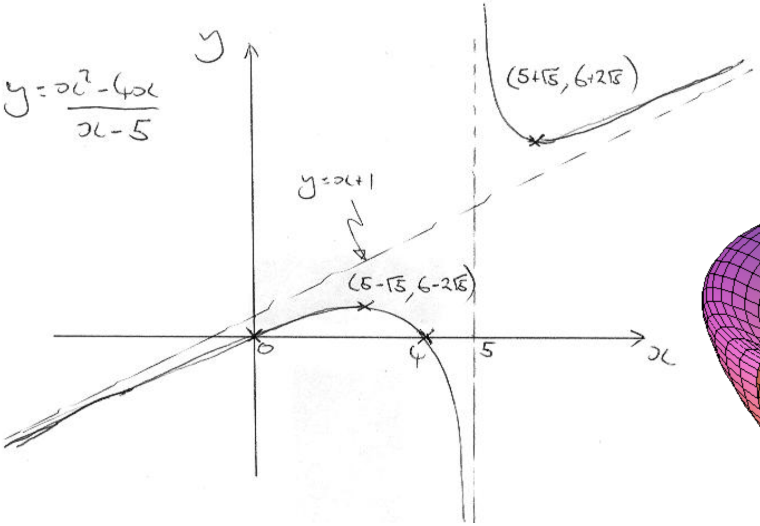
Why Study Mathematics?

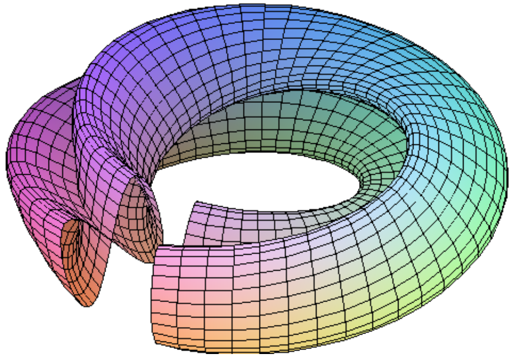
√2 is irrational

- Because of the enjoyment and challenge of solving mathematical problems and understanding mathematical ideas

$$\sum_{n=1}^{\infty}\frac{1}{n^2}=\frac{\pi^2}{6}$$







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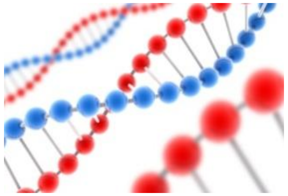
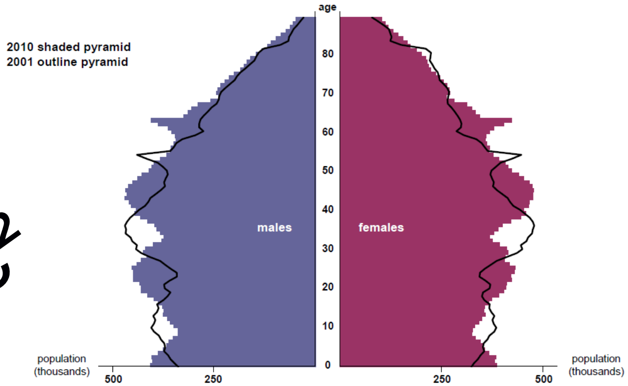
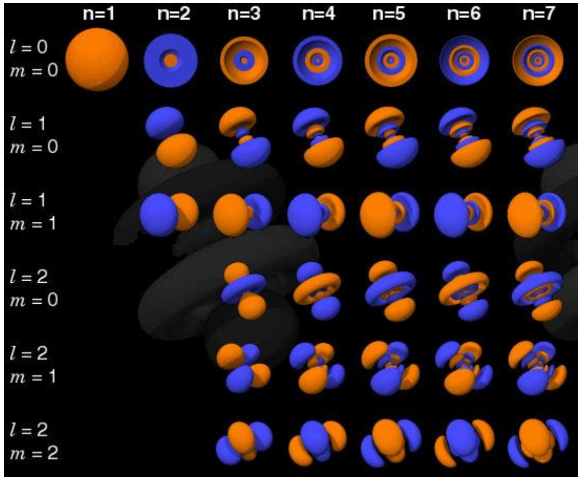


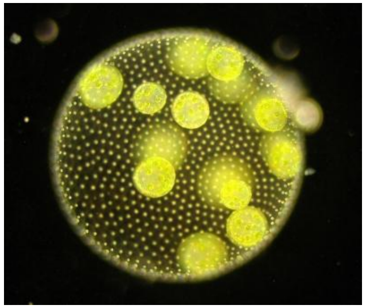
- Because of the enjoyment and challenge of solving mathematical problems and understanding mathematical ideas
- Because it is universal

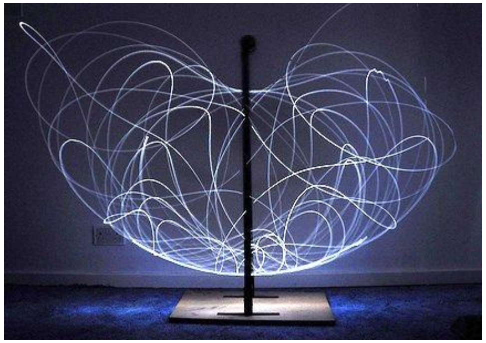
$E=mc^2$



Google







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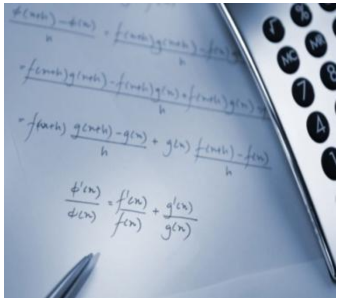
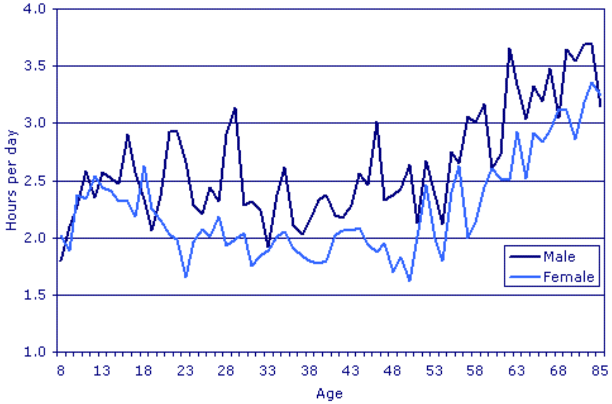


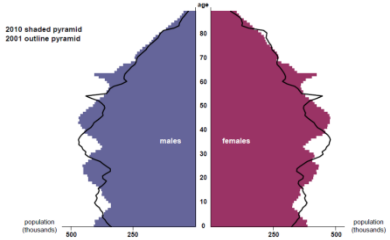
- Because of the enjoyment and challenge of solving mathematical problems and understanding mathematical ideas

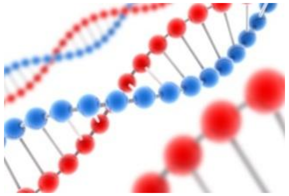
- Because it is universal
- Because of the career opportunities. Employers respect mathematics graduates



Careers in Finance

- Trainee Chartered Accountant: KPMG, Kingston Smith, Goodman Jones
- Investment Analyst: Lane Clark & Peacock
- Trainee Actuary: PriceWaterhouseCoopers, Deloitte
- Credit Risk Analyst: Lloyds Bank, HSBC
- Auditor: Ernst and Young, Grant Thornton



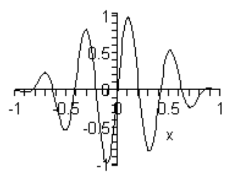
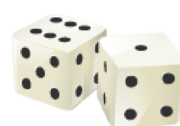
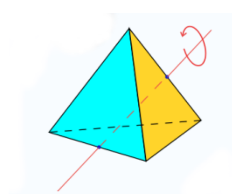


Many other Careers

- Business - Mathematical Modelling, Operations Analysis, …
- Statistics - Medical, Environmental, Market Research, ...
- Teaching - Primary, Secondary, Academic, ...
- Science and Technology - Aerodynamics, Bioinformatics, Cryptography, Digital Signal Processing, Meteorology, ...

MMath/BSc Mathematics

The core takes up Year 1 and about half of Year 2

Tools and Techniques *Follows on naturally from core A-level Mathematics*		Linear Algebra Vector Calculus Differential Equations & Fourier Theory Computational Maths (optional)
Applications *Starting from scratch to allow for different A-level syllabuses*		Probability Statistics Mechanics Financial Maths (optional)
Rigorous Foundations *Goes deeper into the underlying mathematical structures*		Number systems Mathematical Analysis Algebraic Structures Group Theory Geometry (optional)

MMath/BSc Mathematics

Huge range of options after the core (page 1 of 3)

General & Education

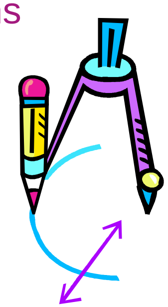
History of Mathematics
School Maths from an advanced (undergraduate) perspective
Mathematics into Schools
Mathematics Education
Maths at Work
Information Skills
Project modules

Foundations

Philosophy of Logic & Maths
Mathematical Logic 1 & 2
Models and Sets
Advanced Logic

Discrete Mathematics

Intro to Discrete Maths
Combinatorics
Graph Theory
Coding Theory

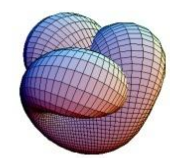


Geometry & Topology

Geometry of Curves & Surfaces
Transformation Geometry
Differential Geometry
Topology
Homotopy & Surfaces

Algebra & Number Theory

Algebraic Structures 2
Number Theory
Groups and Symmetry
Algebra and Numbers
Algebras and Representations
Fields and Galois Theory



Mathematical Analysis

Hilbert Spaces & Fourier Analysis
Linear Analysis 1

Modules available in 2012/13 & 2013/14. Some modules run in alternate years - MMath students can take them in Year 3 or 4

MMath/BSc Mathematics

Huge range of options after the core (page 2 of 3)

Methods of Applied Mathematics

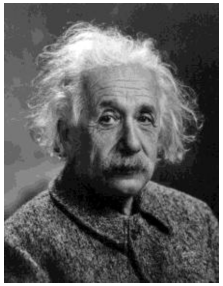
Nonlinear Differential Equations
Calculus of Variations
Mathematical Methods
Dynamical Systems
Analytic Solutions of Partial Diff. Eqns.

Numerical Methods

Numerical Analysis
Numerical Methods
Modern Numerical Methods

Mathematical Physics

Special Relativity
Hamiltonian Systems
Quantum Mechanics
Cosmology
Discrete Systems & Integrability



Fluids & Flow

Fluid Dynamics
Polymeric Fluids
Hydrodynamic Stability
Linear & Non-Linear Waves
Geophysical & Astrophysical Fluid Dynamics

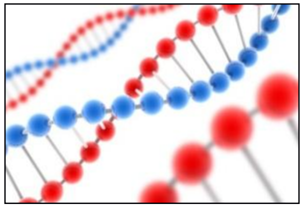
Modules available in 2012/13 & 2013/14. Some modules run in alternate years - MMath students can take them in Year 3 or 4

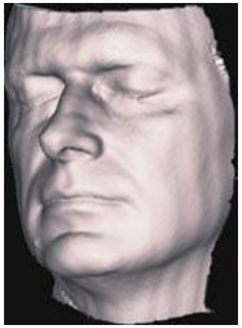
MMath/BSc Mathematics

Huge range of options after the core (page 3 of 3)

Statistics

Statistical Methods
Statistical Modelling
Environmental Statistics
Markov Processes
Survival Analysis
Linear Regression & Robustness
Statistical Theory
Multivariate Analysis
Time Series
Generalised Linear Models
Statistical Shape Analysis
Hidden Markov Models



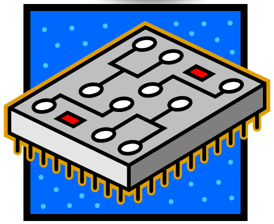


Other Applications of Mathematics

Maths of Music
Financial Maths 1, 2 & 3
Actuarial Maths 1 & 2
Mathematical Biology
Statistics and DNA

Computing

Combinatorial Optimisation
Parallel Scientific Computing
Complexity & Approximation
Statistical Computing



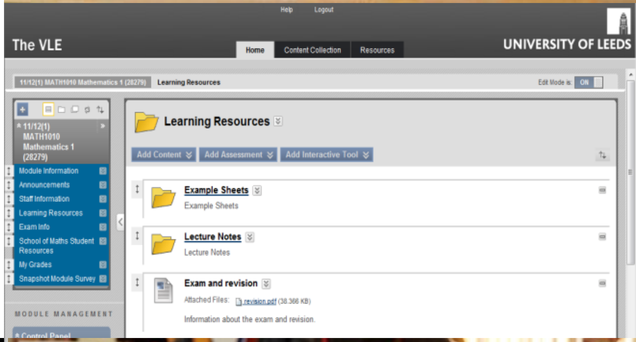
Modules available in 2012/13 & 2013/14. Some modules run in alternate years - MMath students can take them in Year 3 or 4

BSc Mathematics with Finance

	School of Mathematics		Business School
Year 1	Financial Maths Probability Statistics	Calculus & Analysis Linear Algebra Numbers & Vectors Differential Equations	Economic Theory Financial Accounting Management Accounting
Year 2	Financial Maths 2&3 Optimisation	Markov Processes Statistical Methods	Business Finance *+ options from Accounting & Economics*
	+ options from Maths & Statistics		
Year 3	Stochastic Financial Modelling Time Series *+ options from Maths & Statistics*		*Options from Economics & Finance*

How You Study

- **Lectures:** more formal than at school
- **Coursework** for each lecture course, supported by **Tutorials, Workshops & Peer Assisted Learning**
- **Practicals** in computer clusters
- **Projects**: individually and in groups



A Typical Week

MMath/BSc Maths - Year 1

- 12 hours of **Lectures**
- 5 hours of **Tutorials / Workshops / Practicals**
- 1 hour of **Peer Assisted Learning**
- **Coursework** supported by the tutorials

Plus MathSoc, Sport, Union Societies, etc.