



# Scottish Universities Physics Alliance

## *Lasers: The Light Fantastic*

*Wilson Sibbett*

*Wardlaw Professor of Natural Philosophy  
University of St Andrews*

*Jim Hough*

*Director. Institute for Gravitational Research  
University of Glasgow*

*"There cannot be a greater mistake than that of looking superciliously upon practical applications of science. The life and soul of science is its practical application." (Lord Kelvin)*



# *Philosophy to practical science*



- 1666, the visible spectrum explained by *Isaac Newton*
- *The Opticks*, 1704
- *Theory plus experiment* - the beginning of a trend where the philosophy of science gave way to a greater emphasis on the practical aspects of science

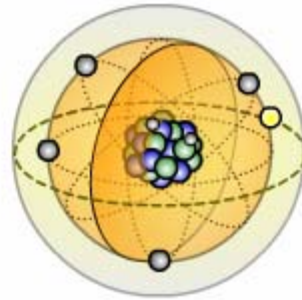
# +200 years to the 1860s - Kelvin



Library of Congress

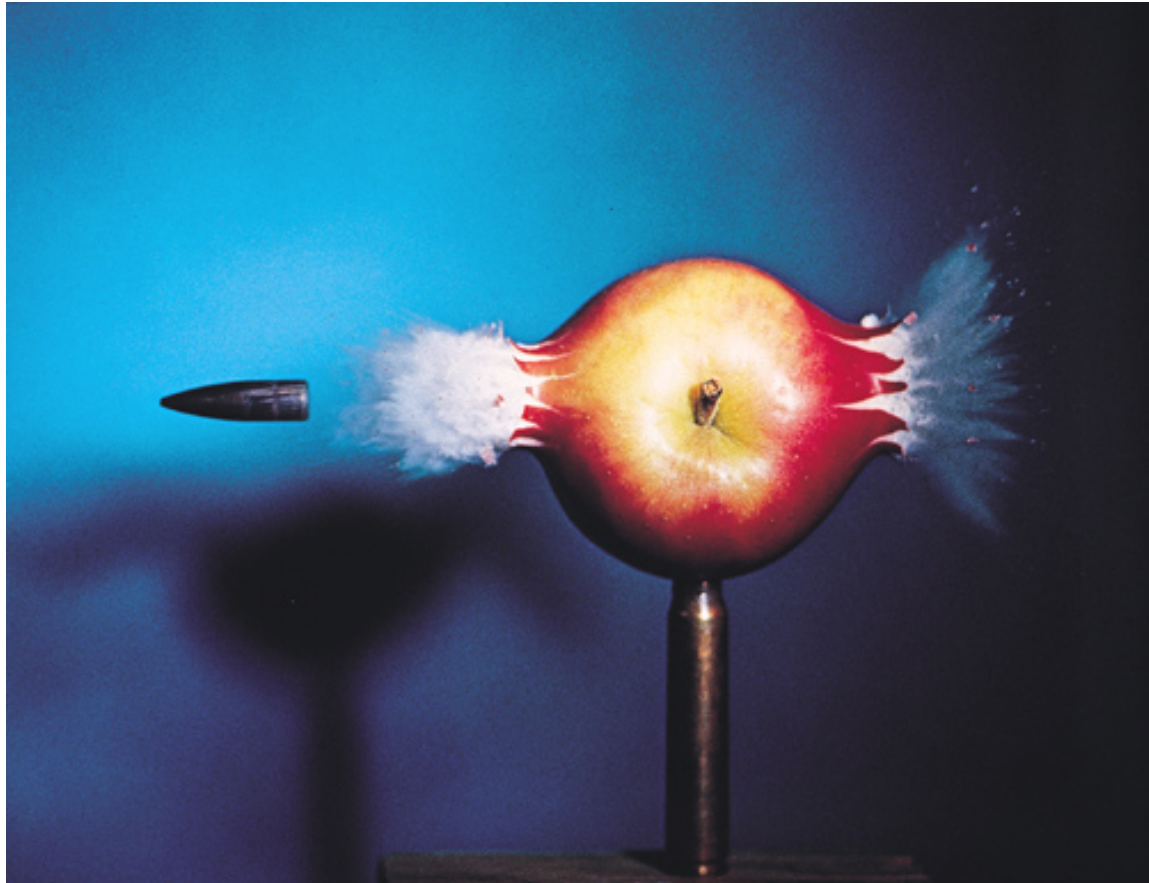
- 1846, Chair of Natural Philosophy in Glasgow University at 22!
- Theory with experiments  
*pioneering days of teaching physics through lectures and practicals!*
- Science to technology  
*interests extended from the fundamentals of science through to engineering and commercial exploitation*

# *Spontaneous & stimulated emission*



# *Novel apple sauce!*

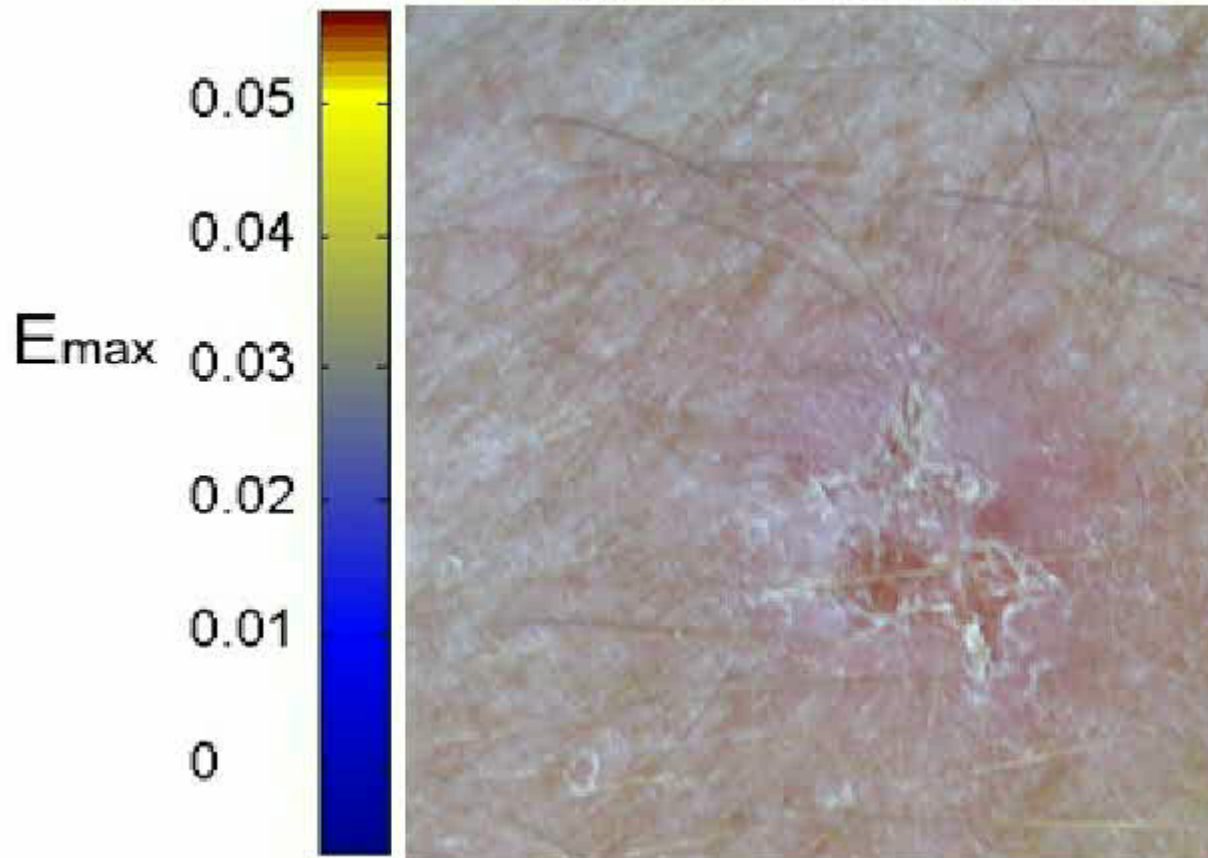
*[Harold Edgerton, MIT, 1964]*



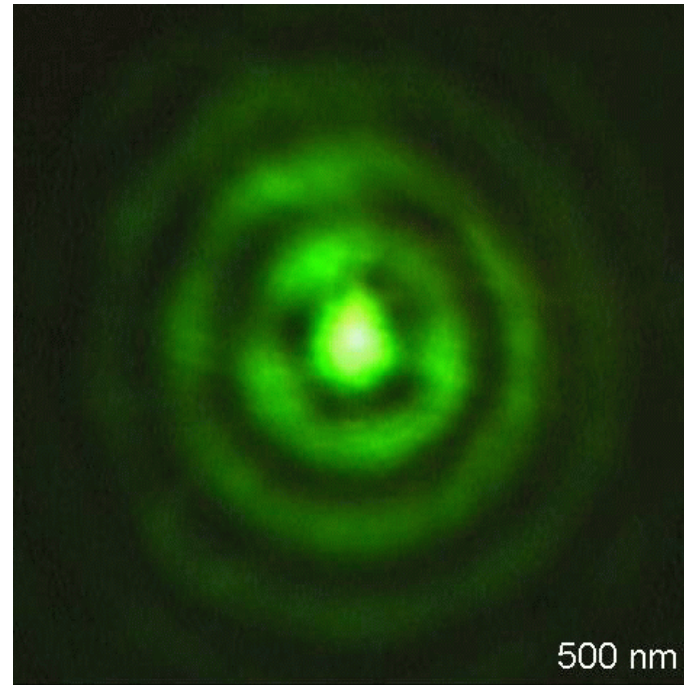
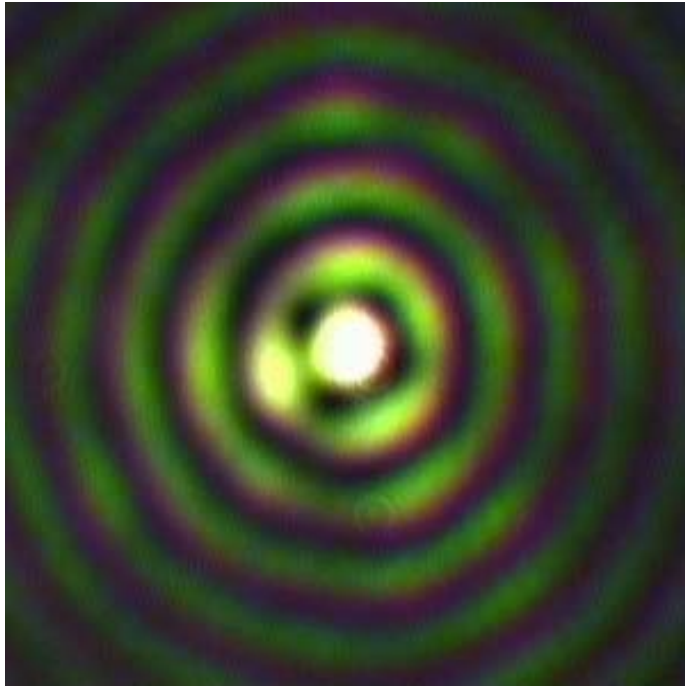
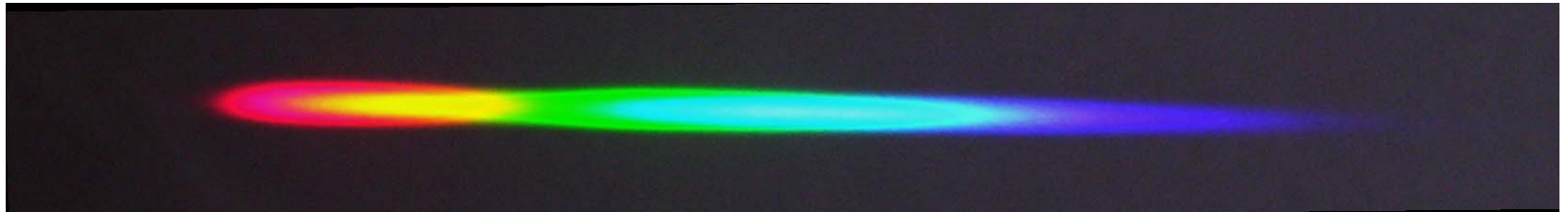
# *Imaging of skin cancer using T-rays*



## Surface Features



# *White light continua in special beams*



# *Treatment of varicose veins*



- *Green laser pulses used with durations matched to thermal relaxation time of the vein*





# *Skin resurfacing using lasers*



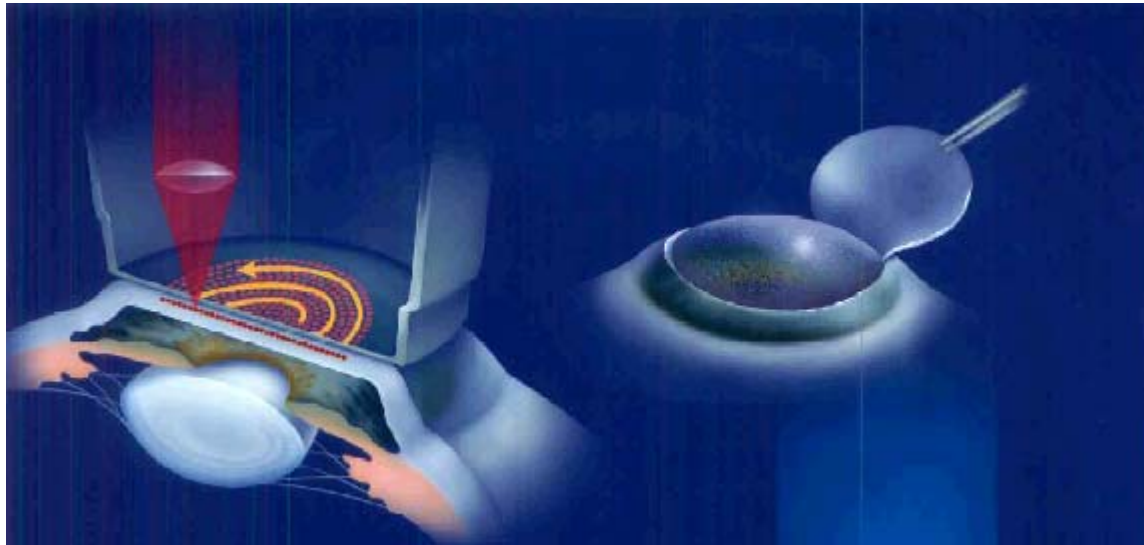
- *Laser skin resurfacing is becoming method of choice  
– preferable to chemical peels or dermabrasion*
- *Pulsed carbon dioxide laser is used*



# *Corrective eye surgery*



- *Laser pulses are used to micro-machine a hinged flap*

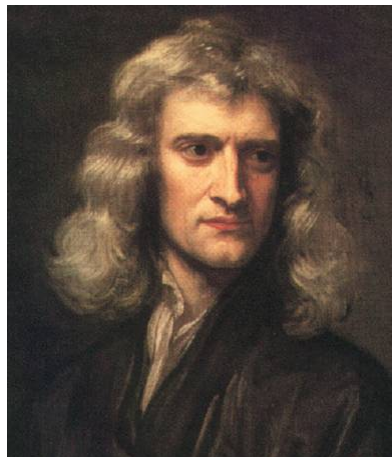
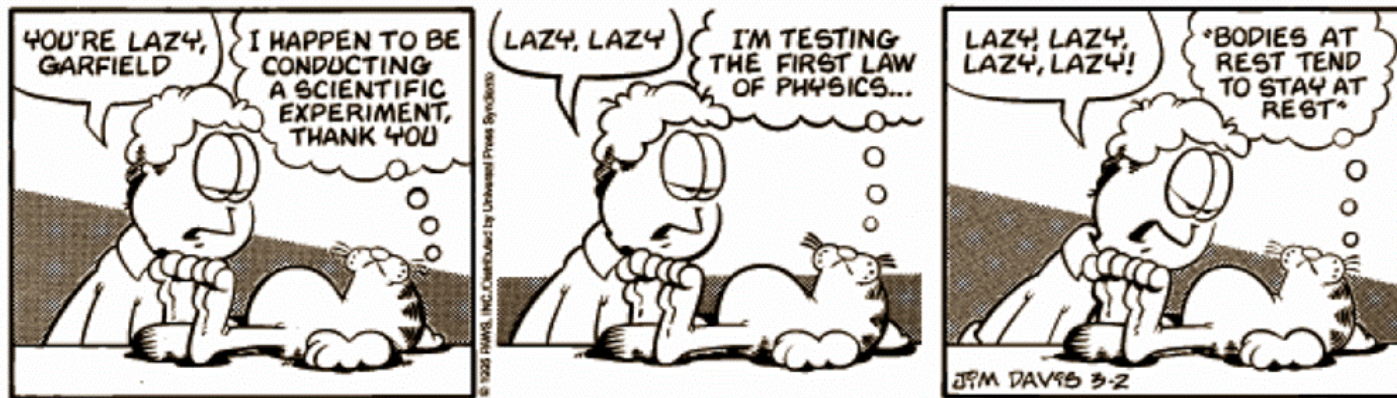


# Lasers – a probe to help understand Gravity



*"I accept no theory of gravitation. Present science has no right to attempt to explain gravitation. We know nothing about it. We simply know **NOTHING** about it."* (Lord Kelvin)

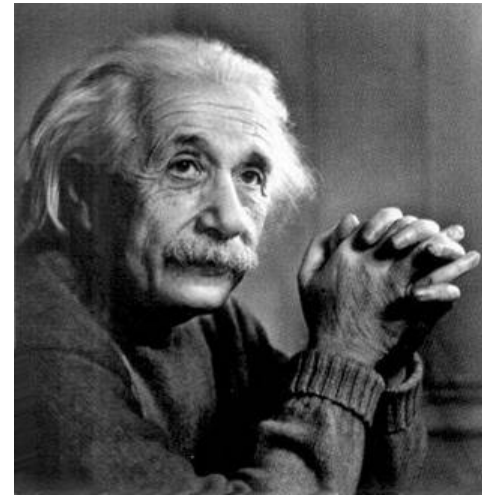
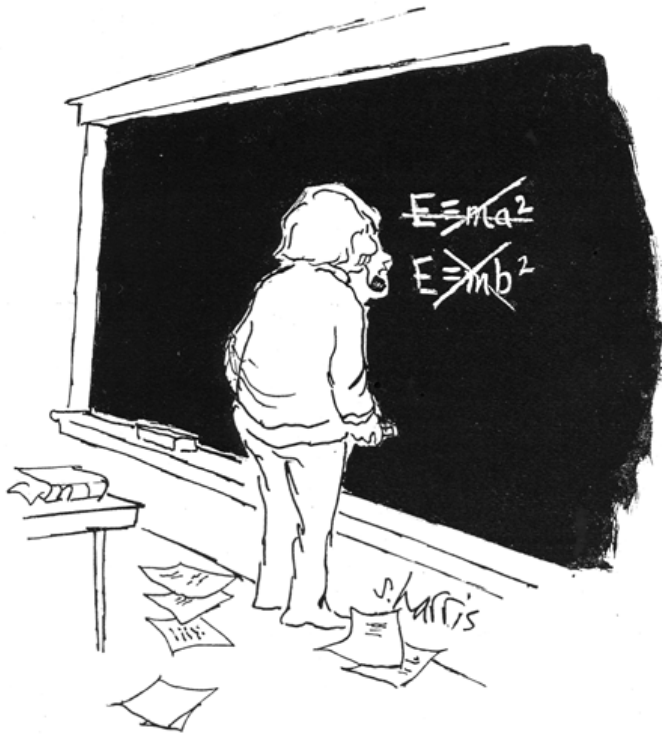
# Newton's Laws



## Newton's Theory

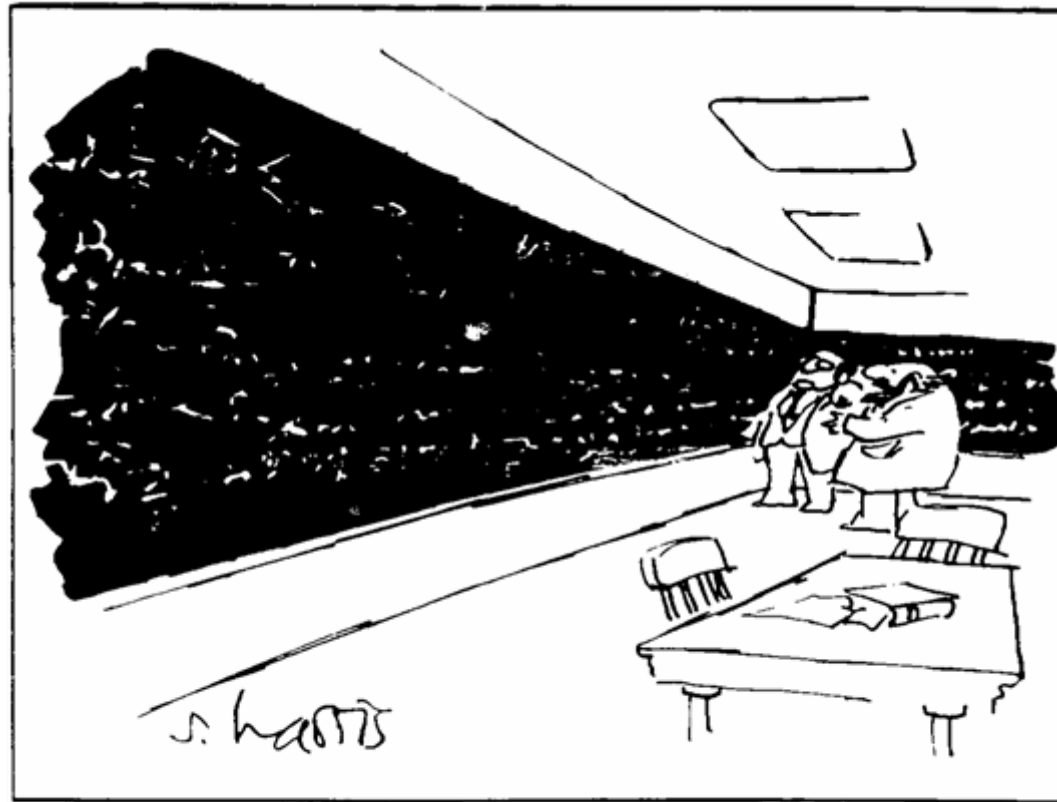
*"instantaneous action at a distance"*

# Einstein's Special Relativity



Einstein's Theory  
*information cannot be  
carried faster than the  
speed of light - so there  
must be gravitational  
waves to carry the  
gravitational effects*

# *What are gravitational waves? – Solution to the Field Equations*



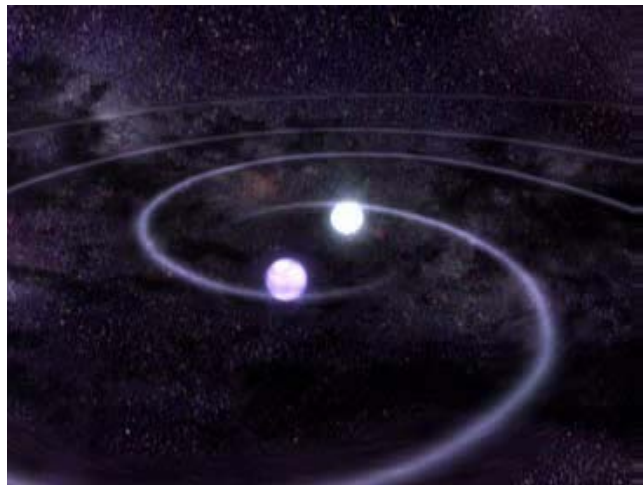
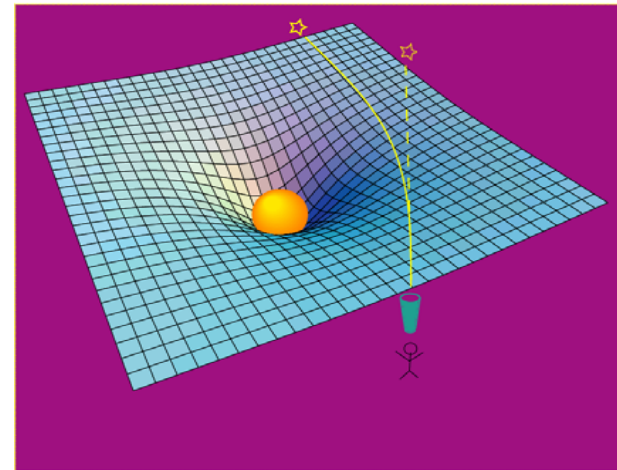
*'But this is just a simplistic way of looking at the problem'.*

© 1989 by Sidney Harris

# 'Gravitational Waves' – easier approach



*"I am never content until I have constructed a mechanical model of the subject I am studying. If I succeed in making one, I understand; otherwise I do not."*  
(Lord Kelvin)

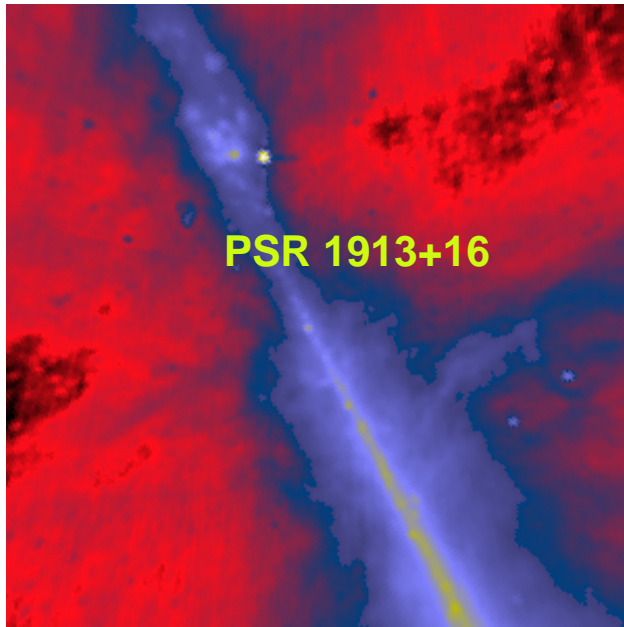


- Gravitational waves  
*'ripples in the curvature of spacetime'* that carry information about changing gravitational fields - or fluctuating strains in space

# The evidence for gravitational waves

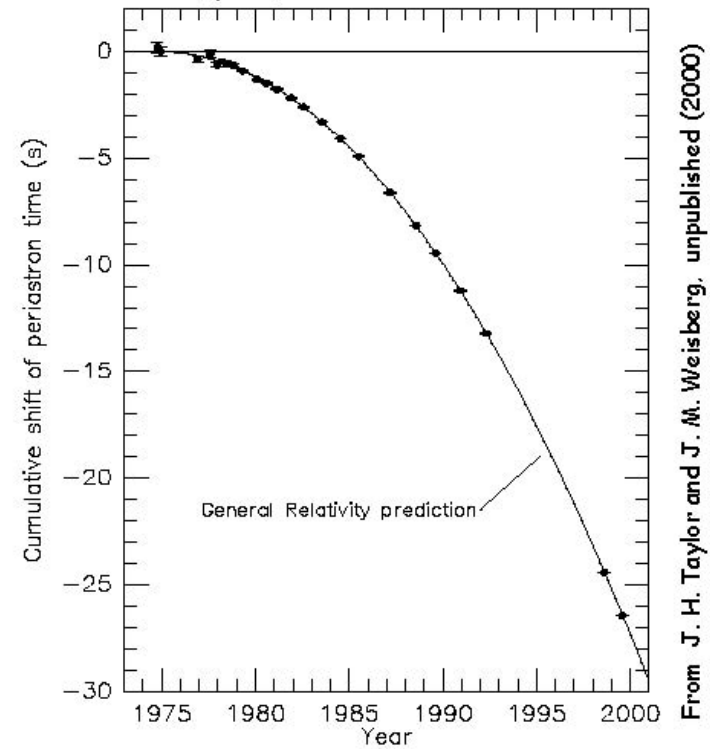


## “Indirect” detection of gravitational waves



*"To measure is to know."*  
(Lord Kelvin)

Comparison between observations of the binary pulsar PSR1913+16, and the prediction of general relativity based on loss of orbital energy via gravitational waves



From J. H. Taylor and J. M. Weisberg, unpublished (2000)



# Einstein in Glasgow 1933



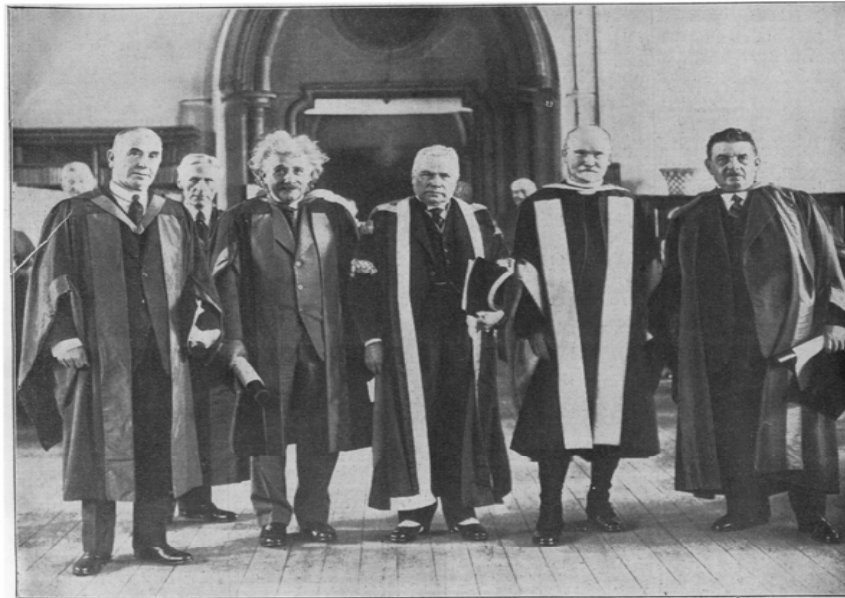
About the Origins of the General Theory of Relativity

by

A. Einstein.

---

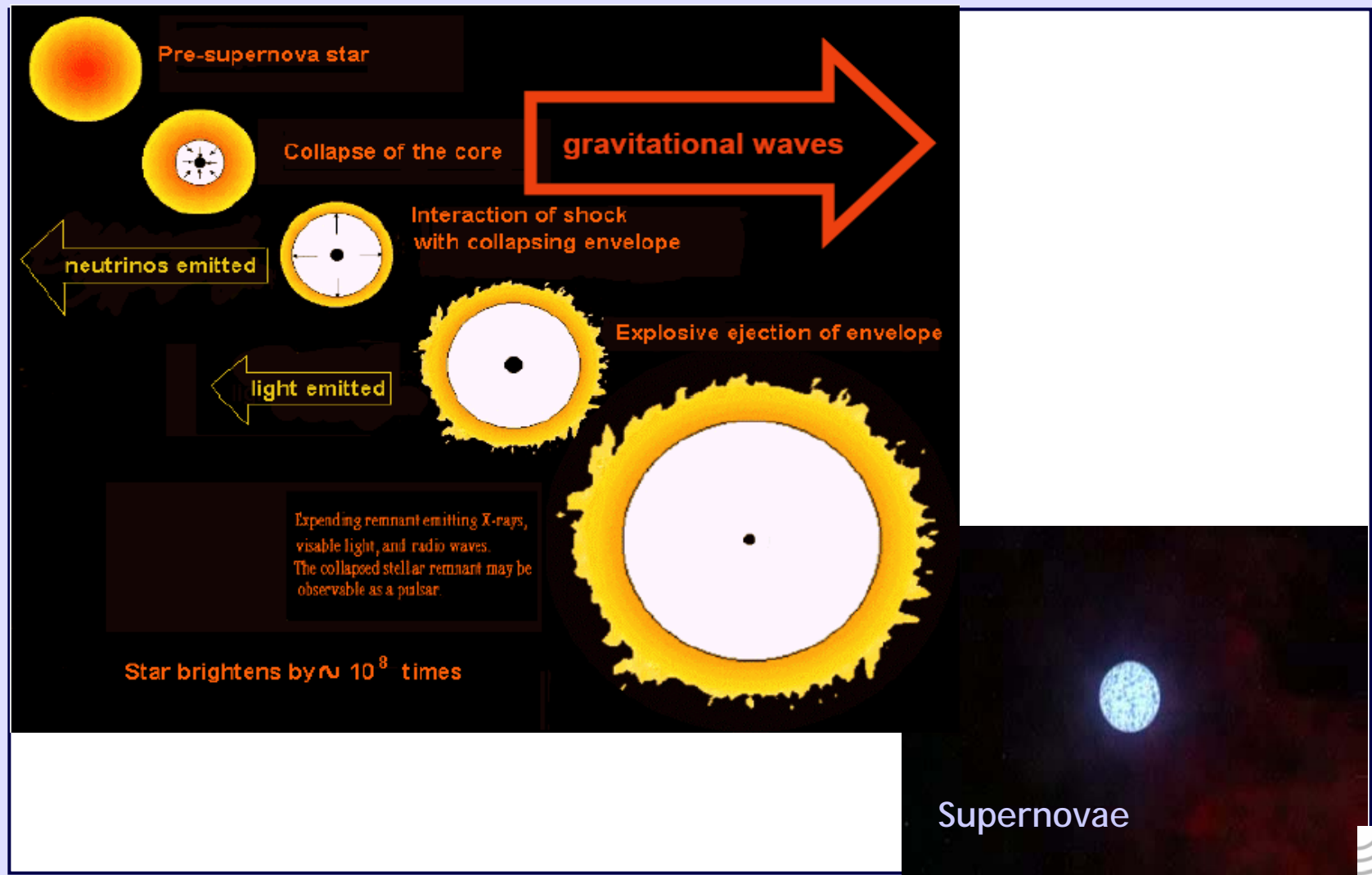
I was very glad to accept the invitation to say something about the history of my own scientific work. Not that I have an unduly high opinion of the importance of my own endeavours. But to write the history of



A group of some of the honorary graduates taken after the ceremony in the Bute Hall of Glasgow University yesterday. Left to right—The Right Hon. Sir Robert S. Horne; Emeritus Professor William Elait-Bell, University of Liverpool; Professor Albert Einstein; Principal Sir Robert S. Rait; the Archbishop of Armagh and Primate of All Ireland; and M. Edouard Herriot, former Prime Minister of France.



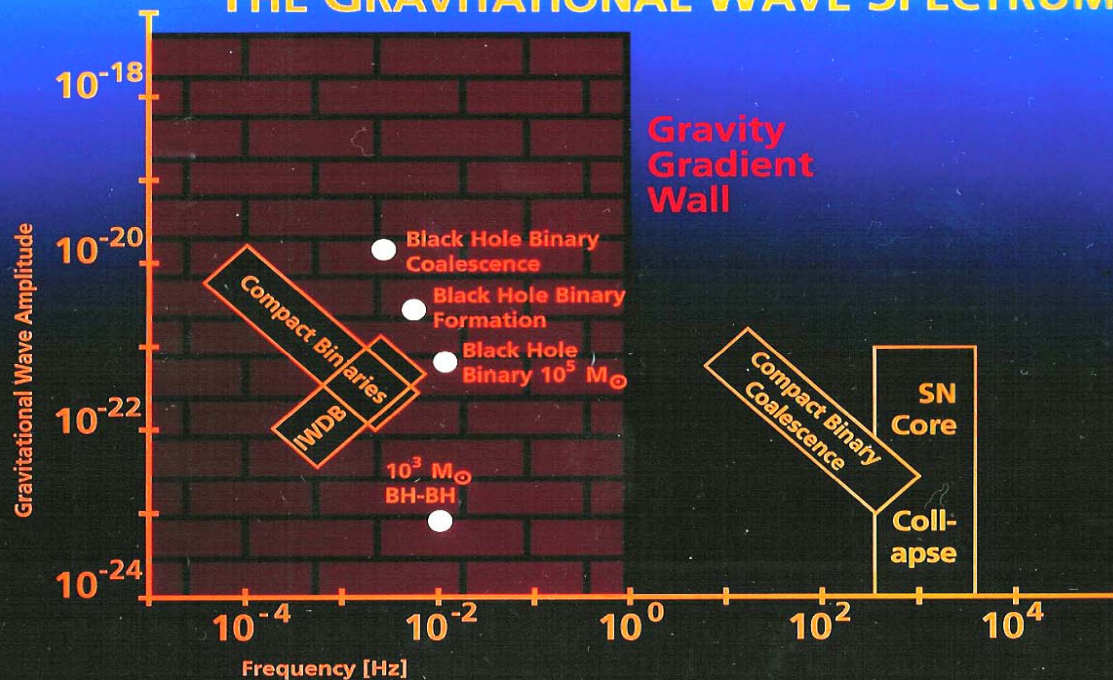
# A Possible Source



# Sources



## THE GRAVITATIONAL WAVE SPECTRUM



Need detectors on ground and in space

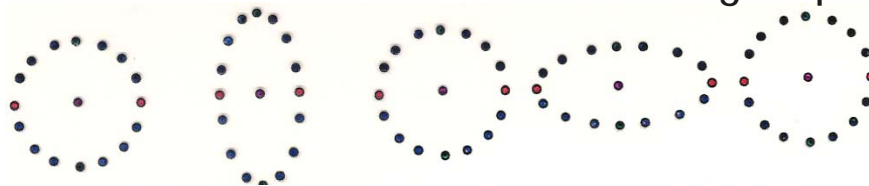
WHY? - **ASTRONOMY** A new window on the Universe



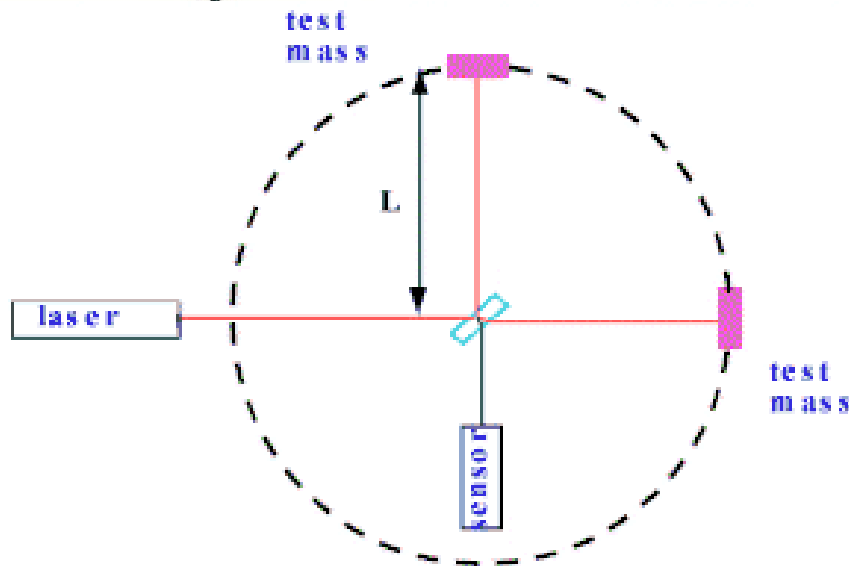
# Detection of gravitational waves using *laser* interferometers - 1



Consider the effect of a wave on a ring of particles :



One cycle



Michelson  
Interferometer

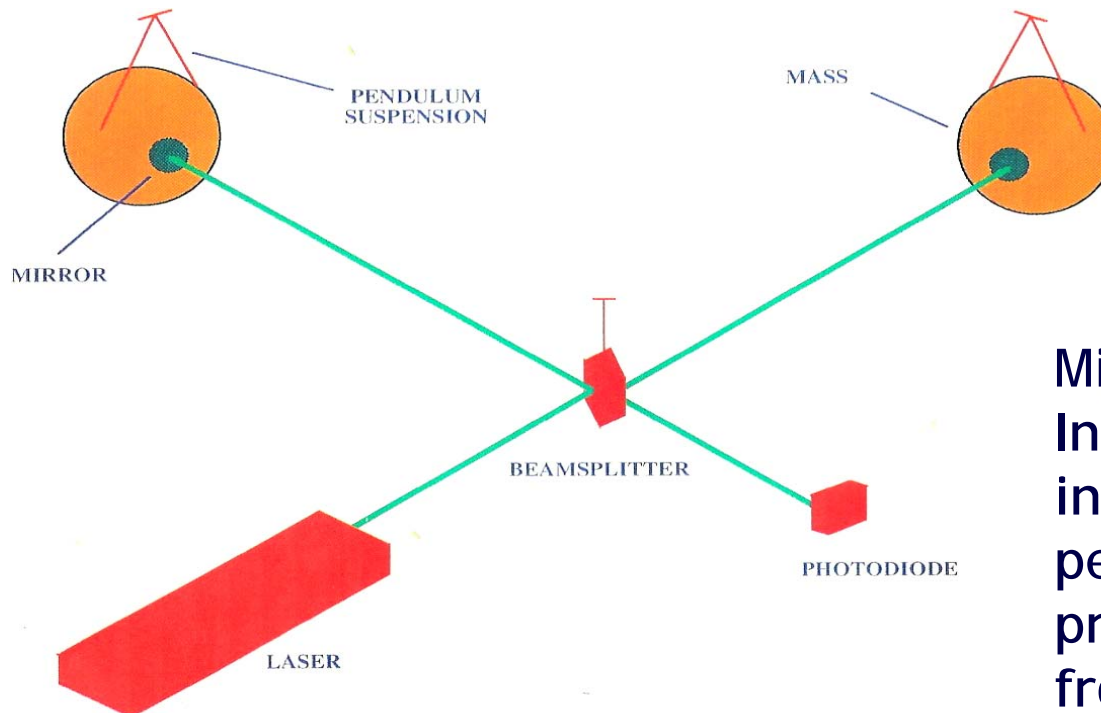
Gravitational waves have very weak effect:

expect movements of less than  $10^{-18}$  m over 4km

# Detection of gravitational waves using *laser* interferometers - 2



*"Physicists are not wholly incapable of appreciating geological difficulties."* (Lord Kelvin)



Michelson Interferometer incorporating use of pendulums to provide isolation from seismic noise

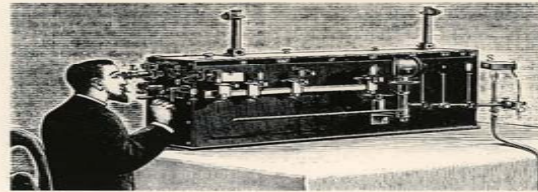
# The Michelson Interferometer



GREAT UNPRONOUNCEABLES  
OF OUR TIME

## MICHELSON'S INTERFEROMETER

The Michelson's Interferometer is as confusing as it sounds. And even more complicated than it looks. Designed to detect minute variations of light velocity through ether in space, it ended up proving that the ether was not there in the first place. Little wonder that the distillers of Bunnahabhain



*(Bu-na-ba-venn)* 12 year old single malt Scotch whisky have no time for such scientific contraptions.

This unique Islay malt defies any attempts to analyse its smooth, subtle qualities. Enjoying it is an art, not a science. And the only complicated part is in the pronunciation.

*Bunnahabhain*  
UNSPEAKABLY GOOD MALT



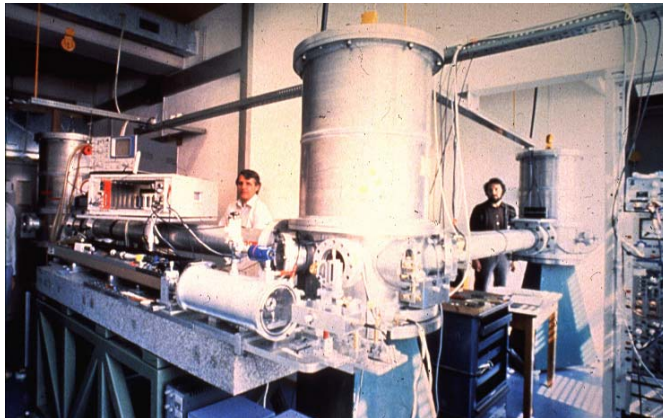
Available at Oddbins, Harrods and Selfridges and selected branches of Victoria Wine, Peter Dominic, Unwins and Augustus Barnett.



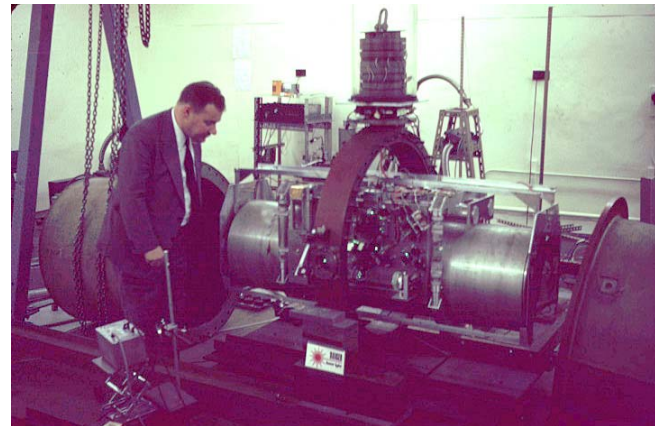
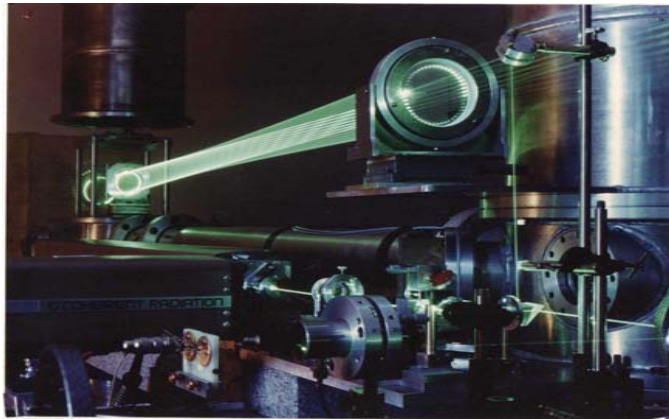
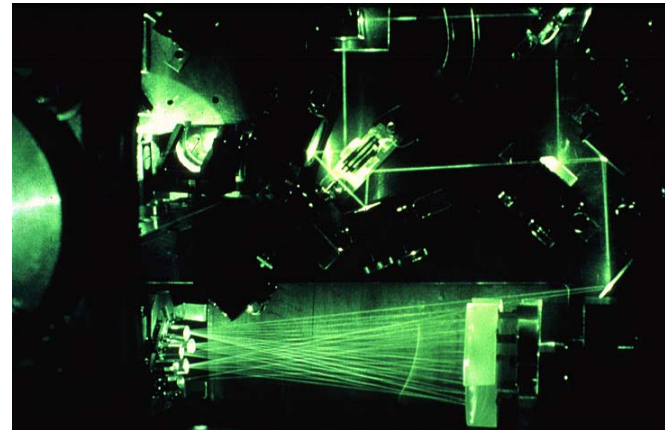
# European Prototypes



## Garching



## Glasgow



# Gravitational wave detector network

*"Large increases in cost with questionable increases in performance can be tolerated only in race horses ...."* (Lord Kelvin)



**LIGO Hanford WA**  
(4km & 2km)



**TAMA (300m)**



**LIGO Livingston LA**  
(4km)

**AIGO**



APS Meeting April 2003

**GEO (600m)**



**VIRGO (3km)**



# Initial LIGO detectors

LIGO project (USA)

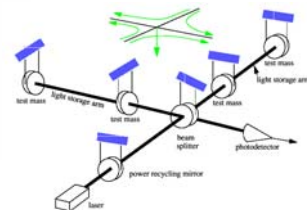
2 detectors of 4km arm length + 1 detector of

2km arm length

- Washington State and Louisiana



Each detector is based on a 'Fabry-Perot Michelson'



Nd:YAG laser  
1.064 $\mu$ m

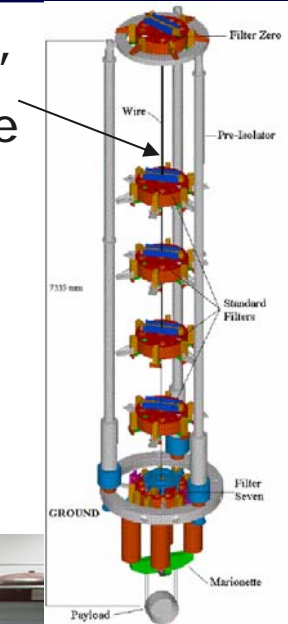
# *VIRGO: French-Italian Project of 3 km armlength at Cascina near Pisa*



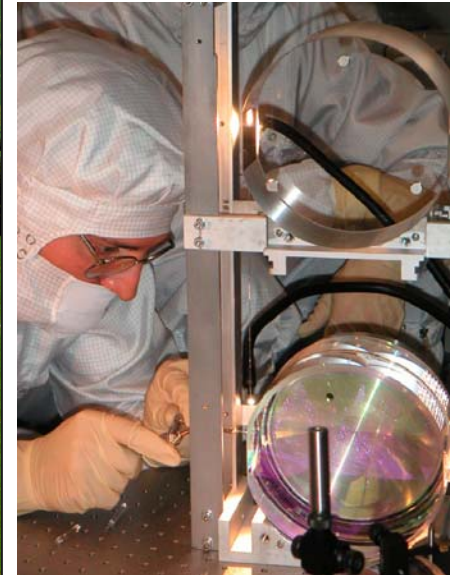
3km beam tube



The 'Super Attenuator' filters the seismic noise above 4 Hz



# *GEO600 - Near Hannover*

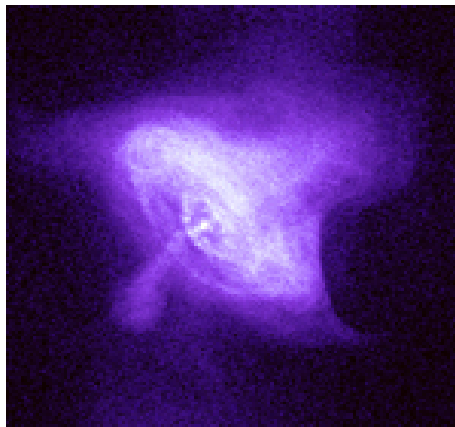


*"There is at present in the material world a universal tendency to the dissipation of mechanical energy." (Lord Kelvin)*

# *What have detectors done so far...*

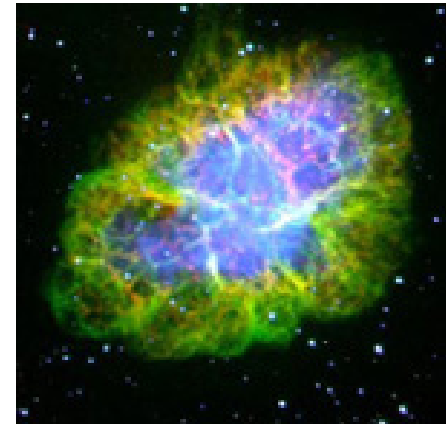
- GEO and LIGO have already made serious searches for gravitational waves
- Have achieved unprecedented levels of precision distance measurement
- Have set new astrophysically significant limits on the signal levels from systems such as the Crab Pulsar
- May well make a detection in the next few years but this cannot be guaranteed

## Crab Nebula



← X-ray image

Optical image →



# *Prospects for Initial LIGO and GEO*

## *– eg coalescing compact binaries*



- Recent discovery of a unique compact binary system in the galaxy:
  - double pulsar J0737-3039 – has improved the statistics for the expected rate of binary coalescences by a significant factors
  - **most probable rate of binary neutron star coalescences detectable by the LIGO system is 1 per 10 years to 1 per 6 hundred years**
- Thus detection at the sensitivity levels of the initial detectors is not guaranteed
  - **need another times 10 improvement in sensitivity**
  - **then most probable rate of binary neutron star coalescences ~10 to 500 per year**

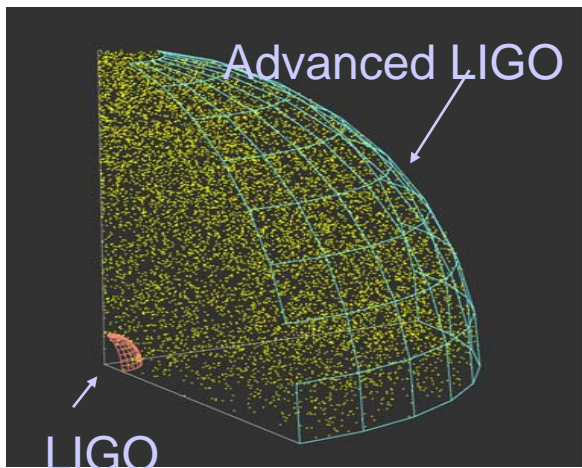
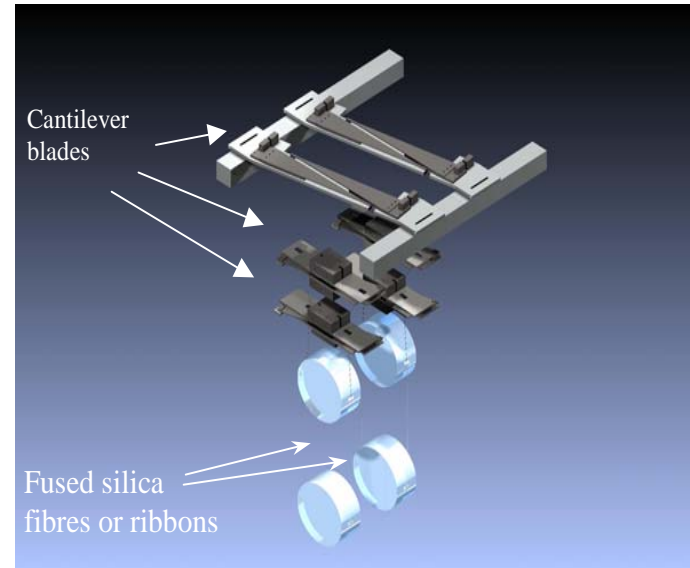


# *For the near future :*

Need to improve sensitivity X10

How?

- can go a long way by **applying the GEO technology** to longer detectors
- better suspensions
- more powerful lasers
- more sophisticated interferometry



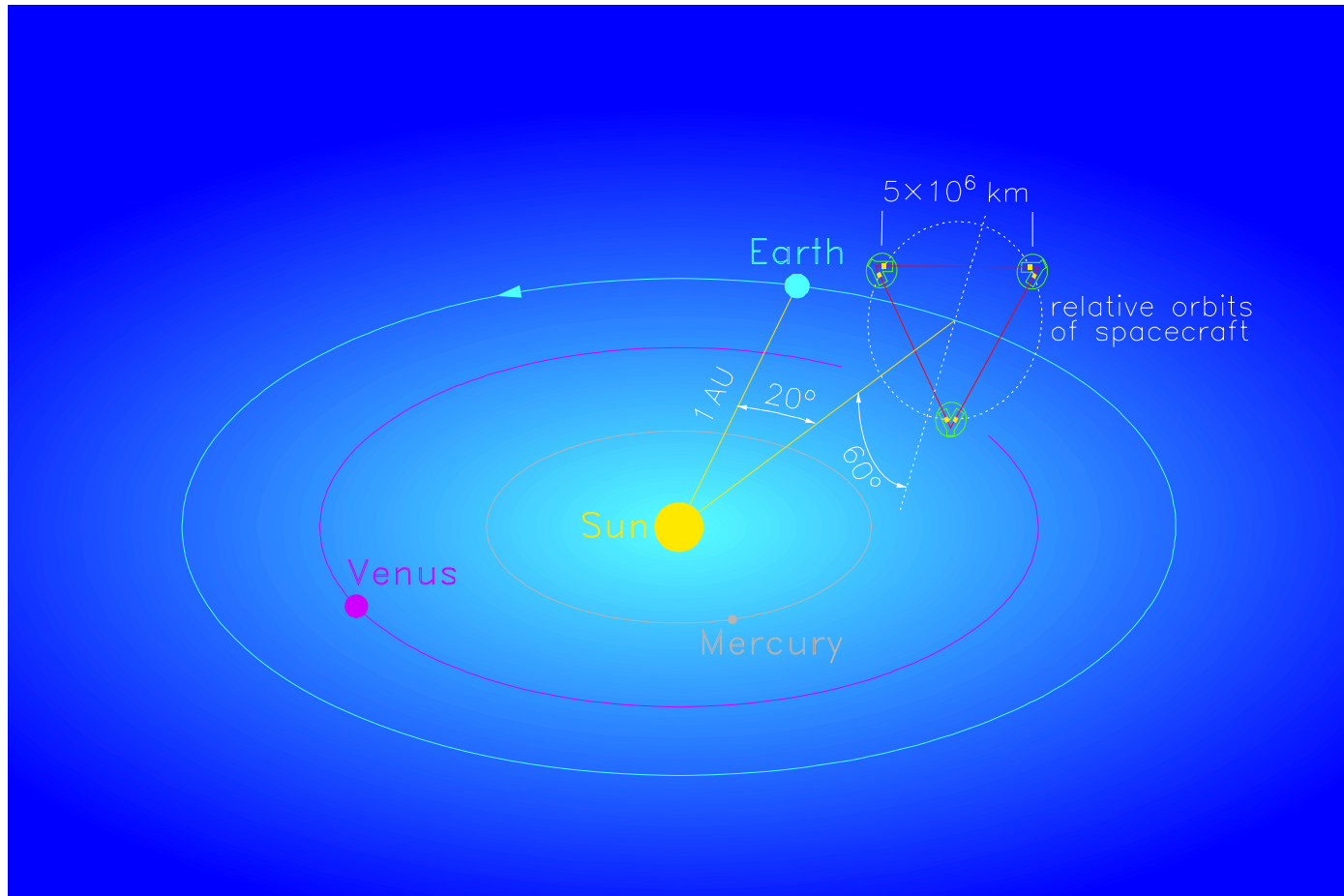
⇒ **'Advanced LIGO'** –

Approved by National Science Board;  
capital contribution from the UK

(~£8 million)

(**Glasgow**, RAL, B'Ham, Strathclyde)

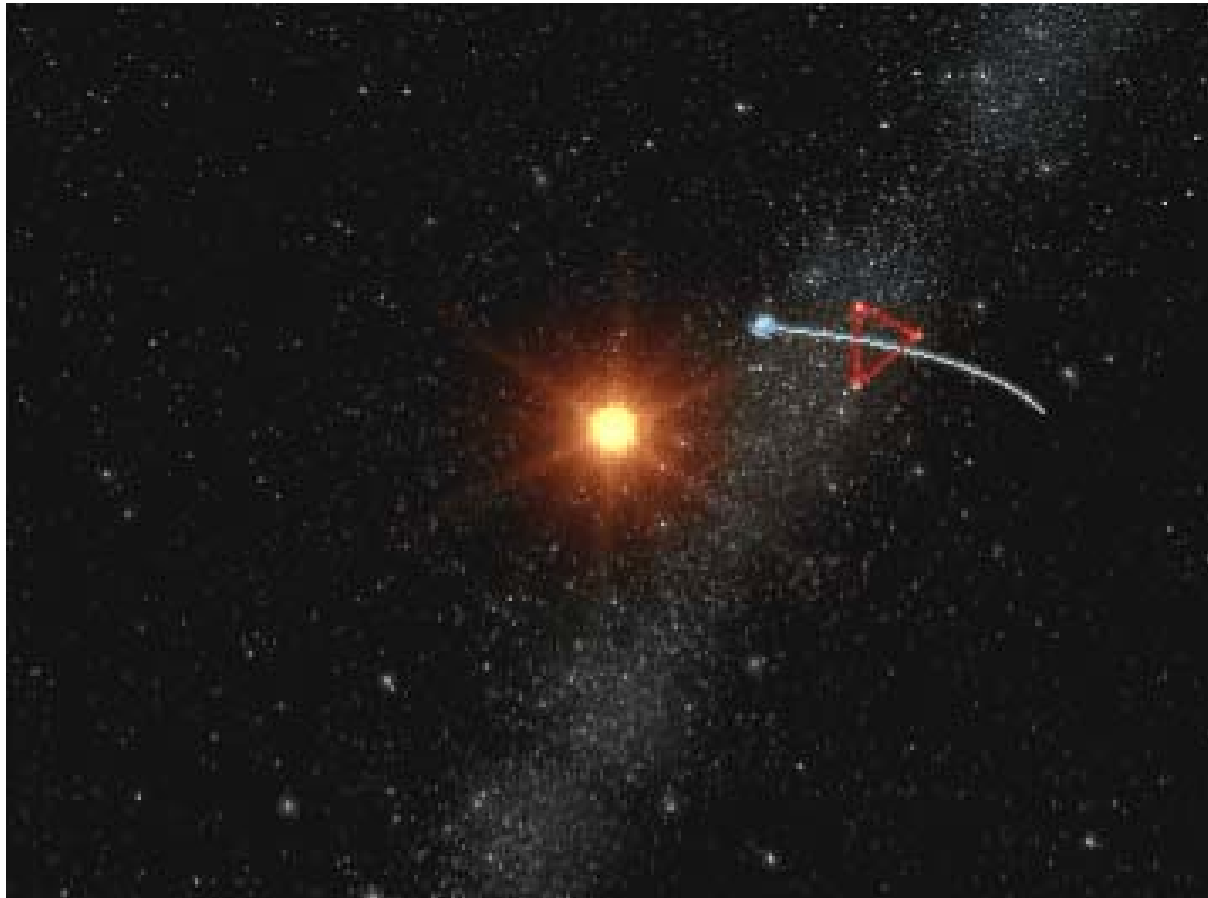
# *LISA – a gravitational wave detector in space*



**LISA**

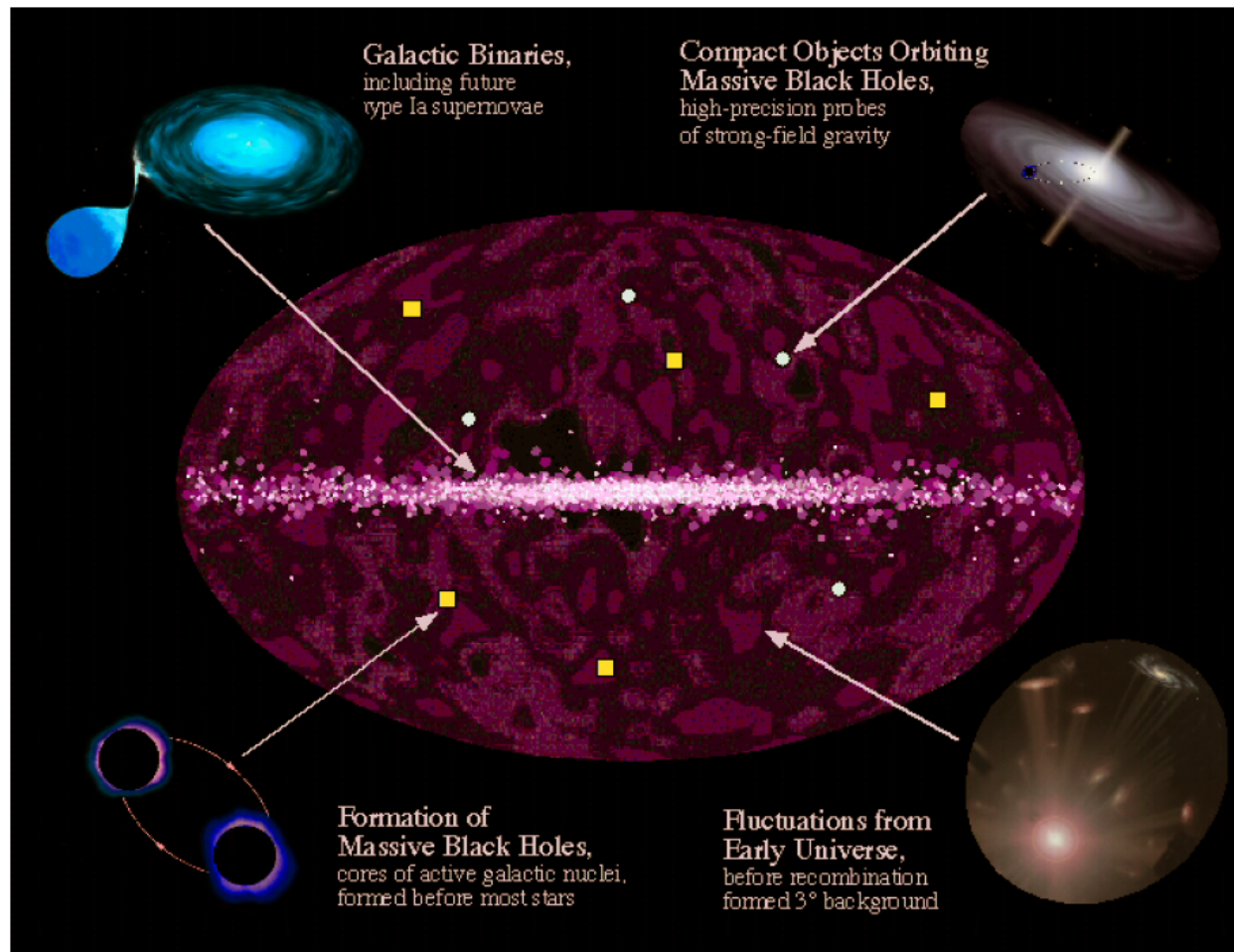


# *LISA's Orbit around sun*

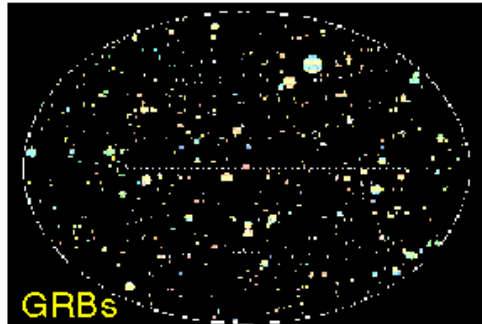
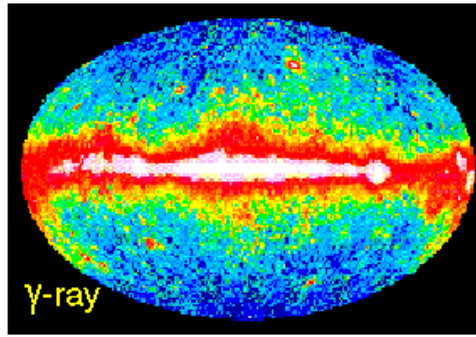
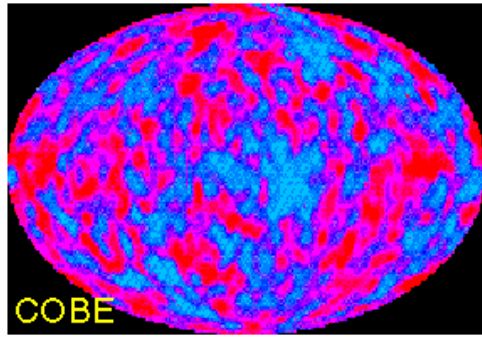
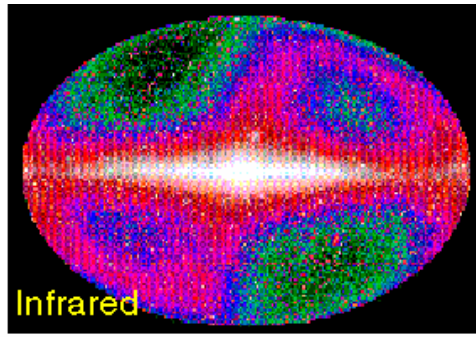
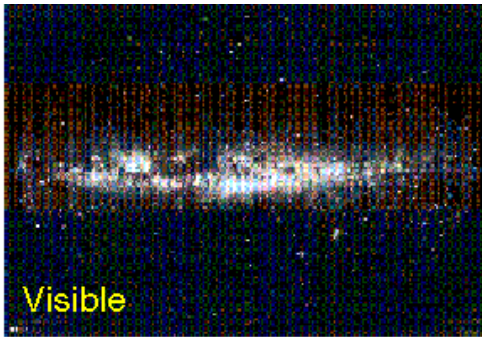




# Sources for LISA



# Gravitational Wave Astronomy

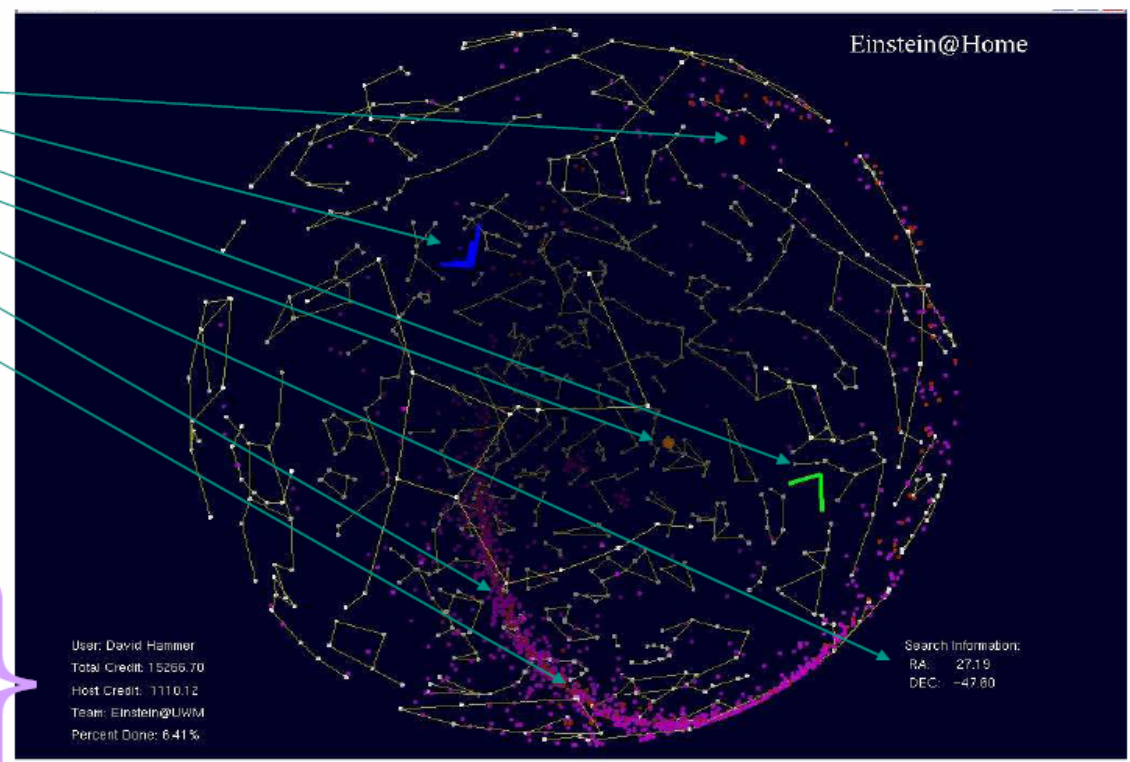


A new way to observe  
the Universe

# You can help - Einstein at Home

- GEO-600 Hannover
- LIGO Hanford
- LIGO Livingston
- Current search point
- Current search coordinates
- Known pulsars
- Known supernovae remnants

- User name
- User's total credits
- Machine's total credits
- Team name
- Current work % complete



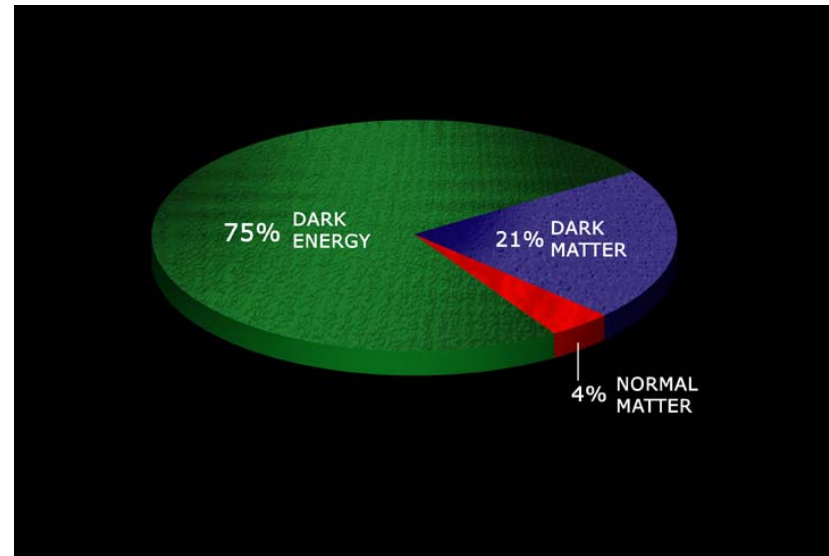
<http://einstein.phys.uwm.edu>

# How much of the Universe is made of matter we understand?



*Approximately 5%*

- There is also
  - “Dark matter” which we can only see through it’s gravitational effects.
  - “Dark energy”, which is causing the Universe to expand and **no-one knows why.**



To help us understand we need new physics ideas, particularly for gravity

*“When you are face to face with a difficulty, you are up against a discovery.” (Lord Kelvin)*