



Introducing Einstein's Universe: Exploring Relativity and Cosmology at High School

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School of Physics and Astronomy, University of Glasgow

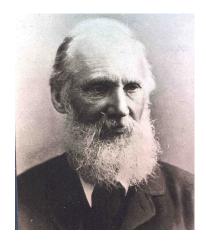


Who am I?...

Senior Lecturer,
Director of Teaching
in the Department of
Physics & Astronomy

(the **Kelvin** Building)





William Thompson (Lord Kelvin) 1824 - 1907









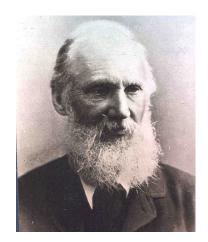


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What do I work on?...

Cosmology: how big is the Universe?

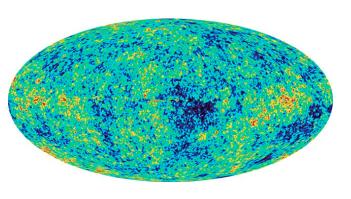
> how did it begin? why is it expanding?

will it expand forever?

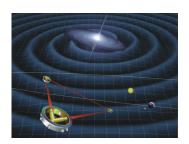


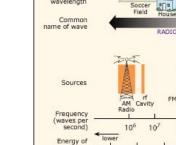
what are black holes and neutron stars? what happens when they collide? was Einstein's picture of gravity correct?

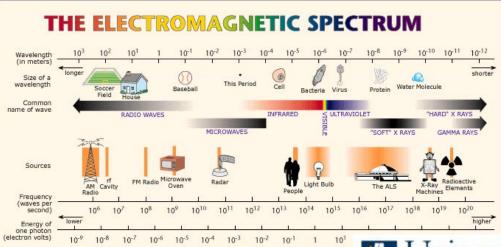




Multi-messenger astronomy



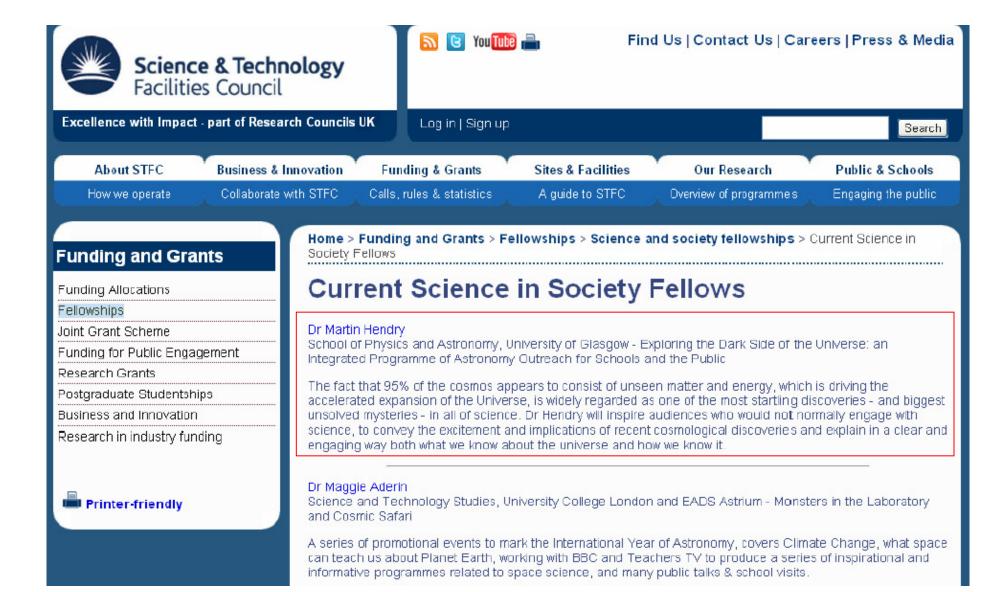


















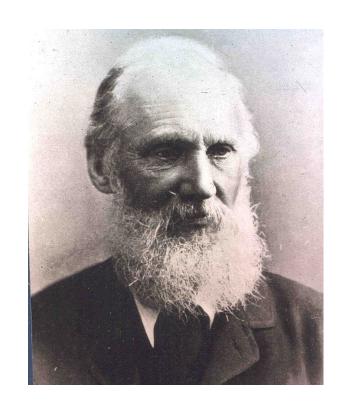


Lord Kelvin didn't always get things right....

1895 "Heavier-than-air flying machines are impossible."

1897 "Radio has no future"

1903 "X-rays will prove to be a hoax"



But he was one of the most influential scientists of all time.









Science:

(From the New Oxford dictionary)

The intellectual and practical activity encompassing the systematic study of the structure and behaviour of the physical and natural world through observation and experiment.



Kelvin's approach put

observation & experiment

at the centre – revolution in

how we teach science,

from pre-school to PhDs









Kelvin believed passionately that:

- Physics is fun
- Physics is fundamental
- Physics is practically useful

"The life and soul of science is its practical application"



"Blow a soap bubble and observe it. You may study it all your life and draw one lesson after another...from it."











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Kelvin's legacy lives on in new developments today





























Sciences Experiences and outcomes

The sciences framework provides a range of different contexts for learning which draw on important aspects of everyday life and work.

Learning in the sciences will enable me to:

- develop curiosity and understanding of the environment and my place in the living, material and physical world
- demonstrate a secure knowledge and understanding of the big ideas and concepts of the sciences
- develop skills for learning, life and work
- develop the skills of scientific inquiry and investigation using practical techniques
- develop skills in the accurate use of scientific language, formulae and equations
- apply safety measures and take necessary actions to control risk and hazards
- recognise the impact the sciences make on my life, the lives of others, the environment and on society
- · recognise the role of creativity and inventiveness in the development of the sciences
- develop an understanding of the Earth's resources and the need for responsible use of them
- express opinions and make decisions on social, moral, ethical, economic and environmental issues based upon sound understanding
- develop as a scientifically-literate citizen with a lifelong interest in the sciences
- establish the foundation for more advanced learning and future careers in the sciences and the technologies.

Key words: "curiosity", "concepts", "inquiry and investigation",

"practical techniques", "accurate use", "impact",

"creativity", "scientifically-literate" citizen.

Much greater emphasis on method than on specific knowledge











New Higher Physics

Designed to promote:

- Deeper understanding of the physics
- Greater emphasis on development of skills
- Open ended enquiry
- Appreciation of topical research

Some streamlining of content, but balanced by more time on 'core' physics + development of research, communication, collaborative skills.









SQA New Higher Physics modules

Our Dynamic Universe

- Equations of Motion
- Forces, Energy and Power
- Collisions and Explosions
- Gravitation
- Special Relativity
- The Expanding Universe
- Big Bang Theory









XSQA New Higher Physics modules

Particles and Waves

- The Standard Model
- Forces on Charged Particles
- Nuclear Reactions
- Wave Particle Duality
- Interference and Diffraction
- Refraction of Light
- Spectra









SQA New Higher Physics modules

Electricity

- Electrons and Energy
- Electrons at Work

Researching Physics











Researching Physics

OUTCOMES

- Research the physics underlying a topical issue to a given brief.
- Plan and carry out investigative practical work related to a topical issue in physics.
- Prepare a scientific communication which presents the aim, results and conclusions from a practical investigation related to a topical issue in physics.









Outline of this session

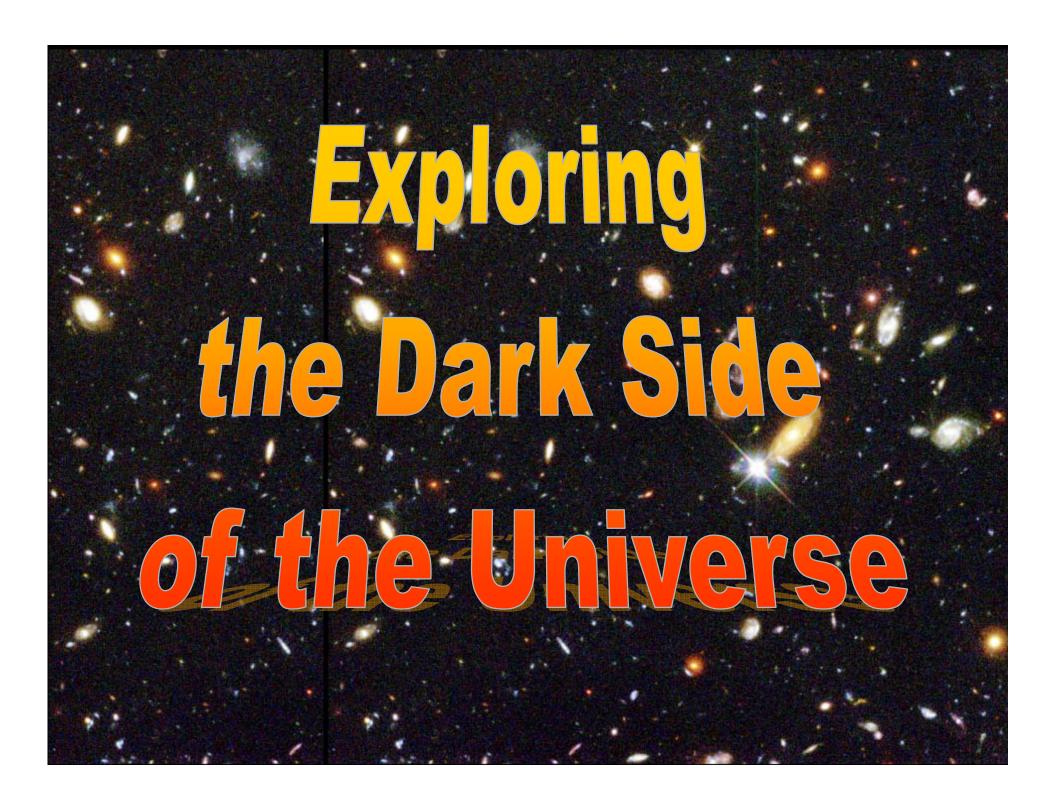
- Update on current developments in cosmology and astrophysics
- Discussion of possible themes / approaches for Researching Physics module.
- Plan for turning ideas into practical exercises.
 (Timescale: late spring 2011. Any willing 'road testers'?...)







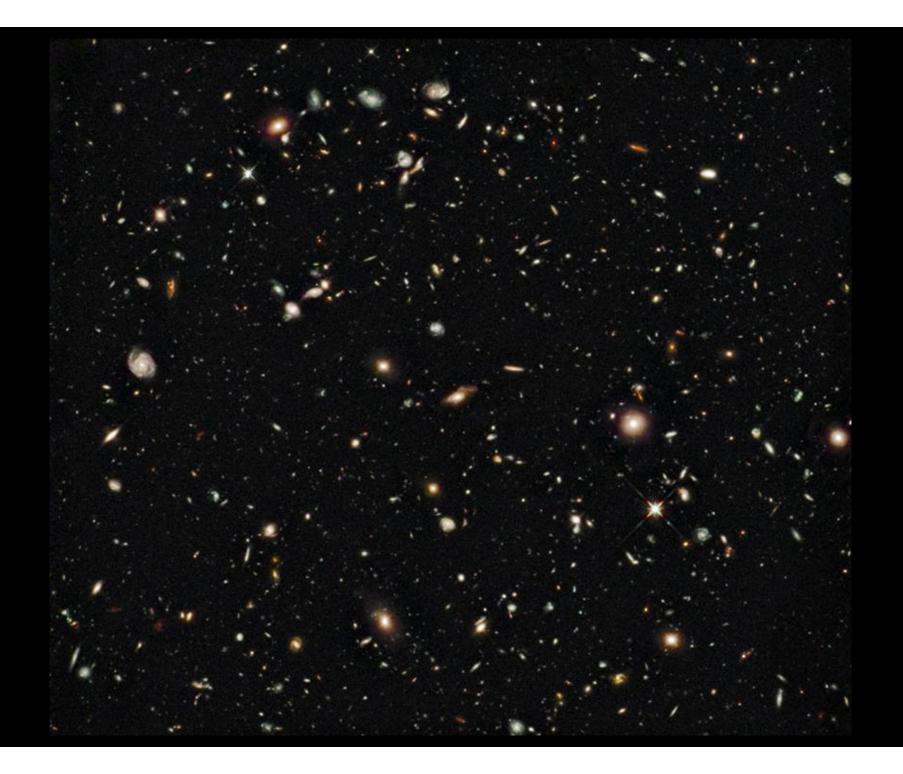






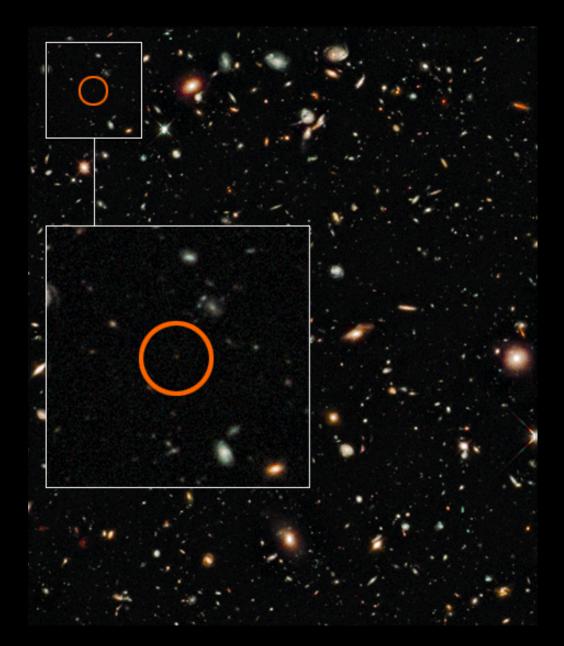
A long time ago,

in a galaxy far, far away...

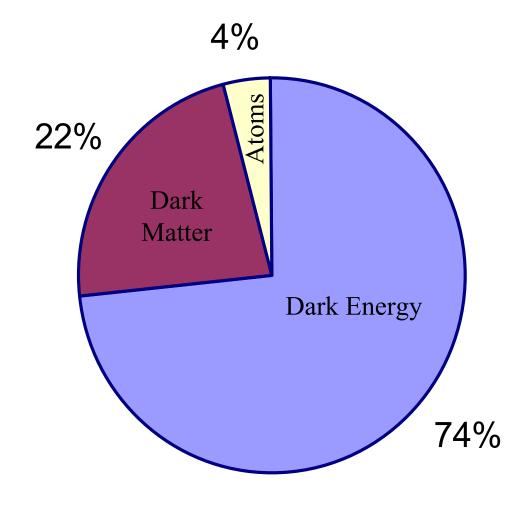








State of the Universe – Nov 2010











National Course Specification: course details (Proposed Unit)

Higher Physics: Our Dynamic Universe

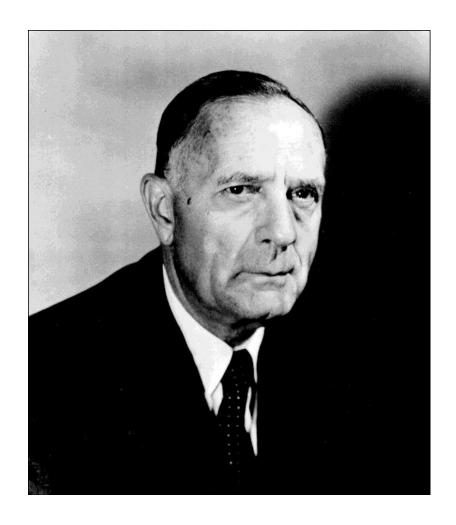
6. The expanding Universe			
a)	The Doppler Effect and redshift of galaxies.	The Doppler Effect is observed in sound and light. For sound, the apparent change in frequency as a source moves towards or away from a stationary observer should be investigated. The Doppler Effect equations used for sound should not be used in the case of light from fast moving galaxies. This is because of relativistic effects. The redshift of a galaxy is the fractional difference between the observed wavelength and the wavelength that would be observed if the object were standing still. For closer galaxies redshift is the ratio of the velocity of the galaxy to the velocity of light.	Doppler Effect in terms of terrestrial sources e.g. passing ambulances. Investigating the apparent shift in frequency using a moving sound source and datalogger. Applications include measurement of speed (radar), echocardiogram and flow measurement.
b)	Hubble's Law.	Hubble's Law shows the relationship between the recession velocity of a galaxy and its distance from us. Calculations using Hubble's constant should be carried out using SI units. Hubble's Law leads to an estimate of the age of the Universe.	Measuring distances to distant objects. Parallax measurements and data analysis of apparent brightness of standard candles. An astronomical perspective may be gained by consideration in terms of kms ⁻¹ per million light years.
с)	Evidence for the expanding Universe.	Data of the velocity of distant celestial objects leads to the theory of the expanding Universe. Gravity is the force which slows down the expansion. The eventual fate of the Universe depends on its mass. Measurements of the mass of galaxies lead to the conclusion that there is significant mass which cannot be detected – dark matter. Measurements of the expansion rate of the Universe lead to the conclusion that the expansion rate is increasing, suggesting that there is something that overcomes the force of gravity – dark energy.	Data analysis of measurements of galactic velocity and distance. The unit 'Particles and Waves' includes an investigation of the inverse square law for light. Centres may wish to include this activity in this topic. The history of how we learned the structure of the Milky Way, including its size and the average density of stars is a useful way to approach estimating the mass of a galaxy. This avoids reference to estimating mass using rates of rotation.
			The work of Einstein and in particular his description of his 'greatest blunder' is a useful way to explore the concept of dark energy.



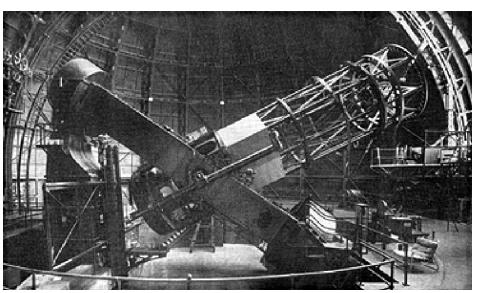


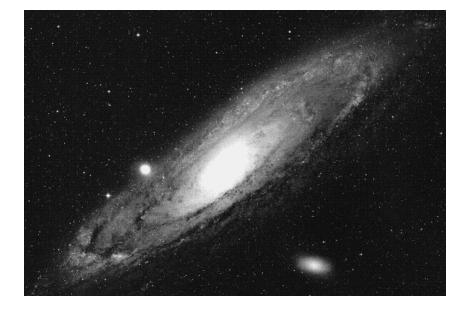






Edwin Hubble





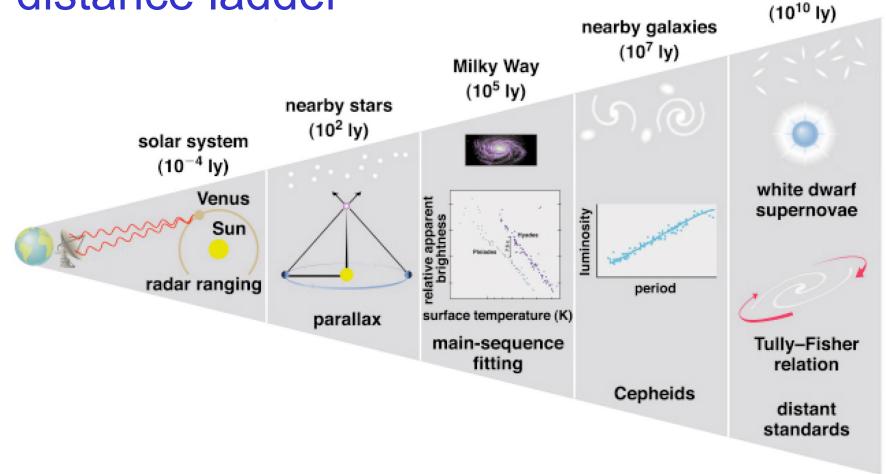








The Cosmic distance ladder





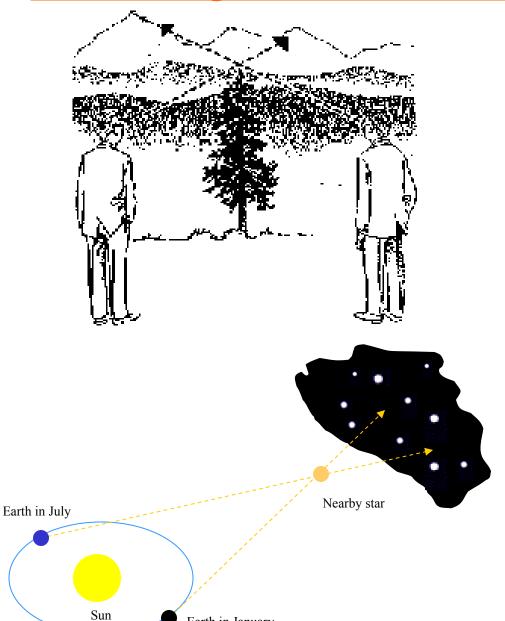




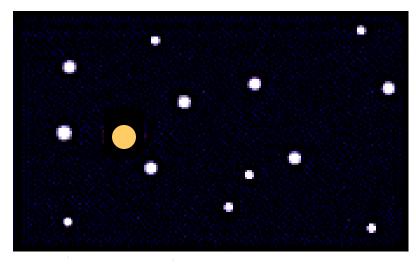


galaxy clusters

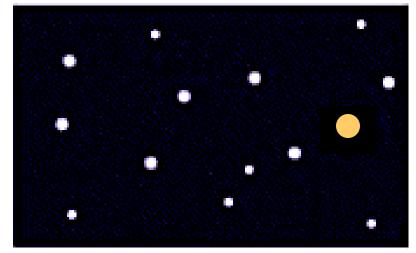
Measuring Astronomical Distances: Parallax



Earth in January

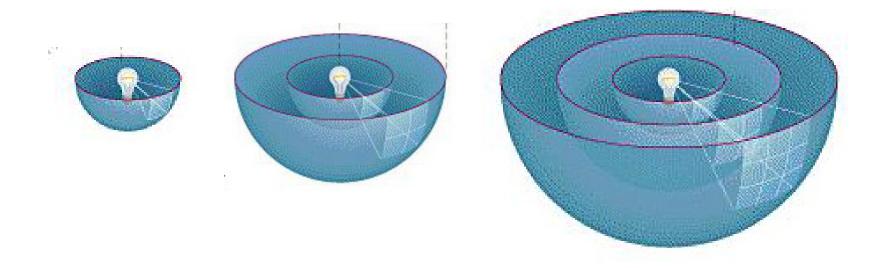


View from the Earth in January



View from the Earth in July

We can use the Inverse-Square Law



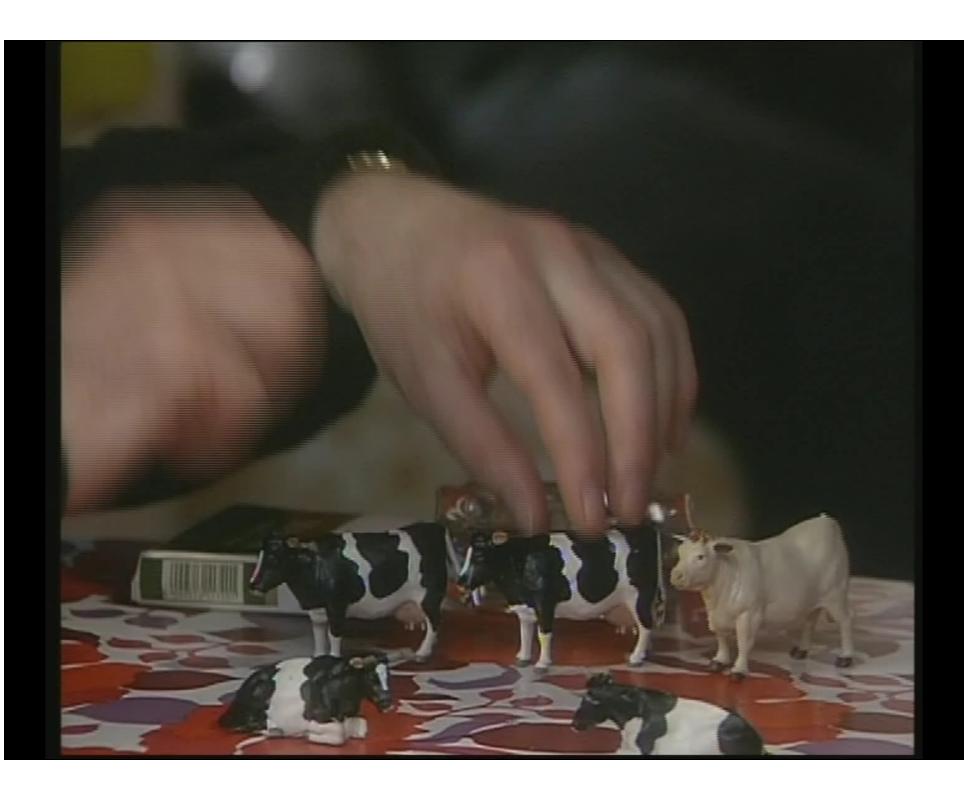
Apparent brightness, or flux, falls off with the square of the distance, because the surface area of a sphere increases with the square of its radius



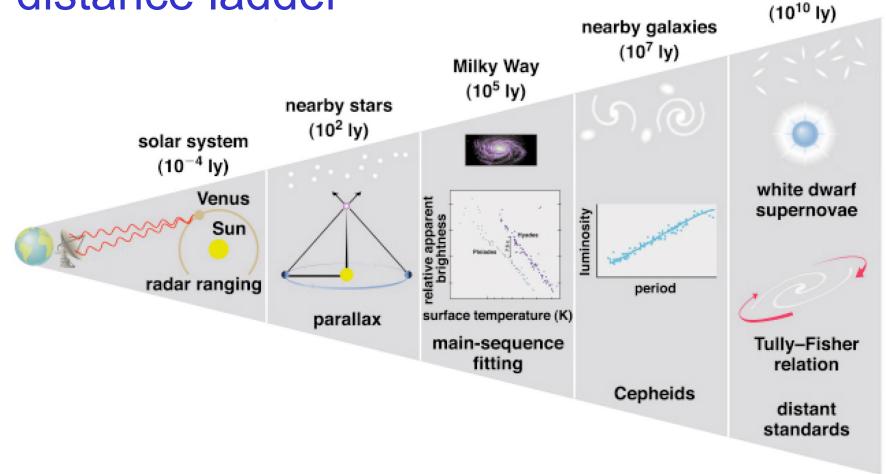








The Cosmic distance ladder



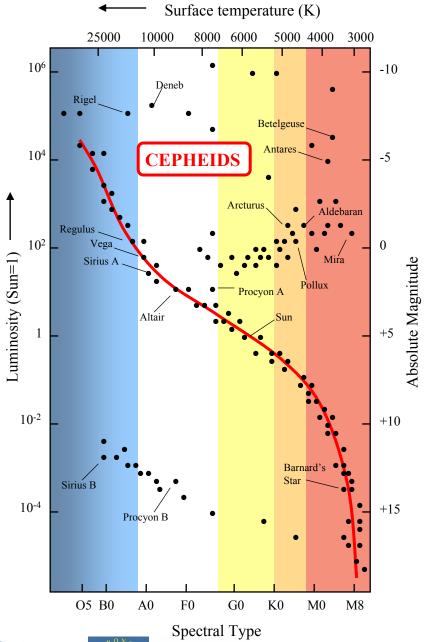








galaxy clusters



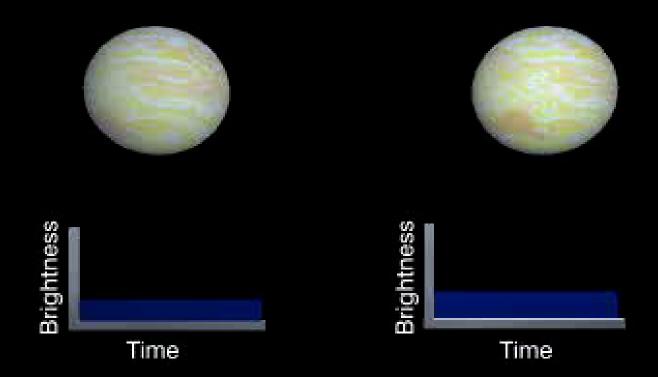












The brighter the Cepheid, the longer it takes to pulsate.

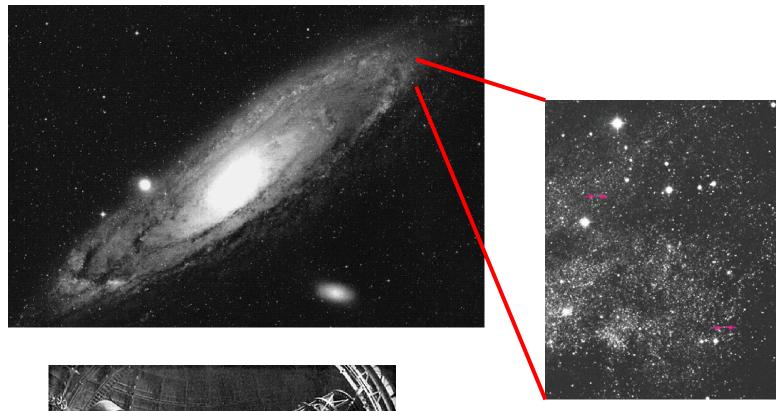
So by measuring a Cepheid's pulsation period we can estimate its true brightness

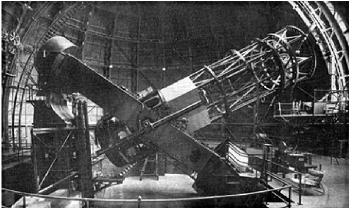












1922: Hubble finds Cepheids in the Great Nebula in Andromeda





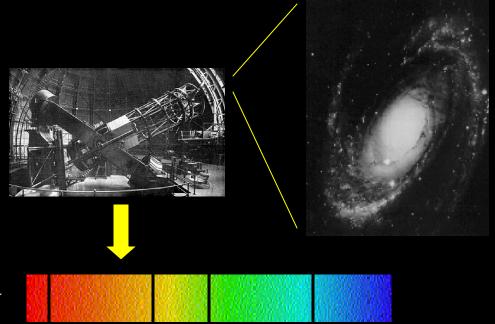




Hubble measured distances to dozens of nearby nebulae

Even the nearest, in Andromeda, was millions of light years distant

Hubble also measured the shift in colour, or *wavelength*, of the light from distant galaxies.





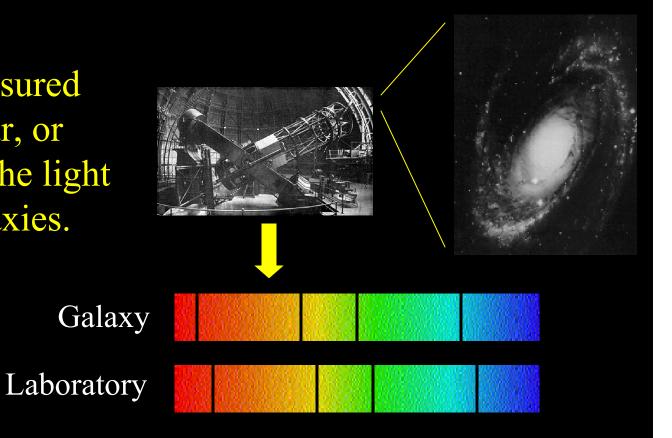








Hubble also measured the shift in colour, or *wavelength*, of the light from distant galaxies.



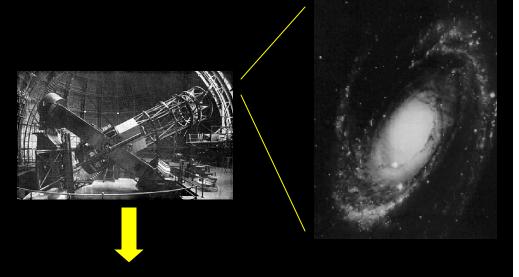








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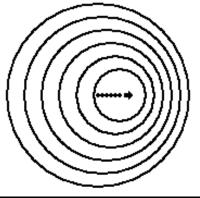


Galaxy

Laboratory







OBJECT APPROACHING: SHORT BLUE WAVES



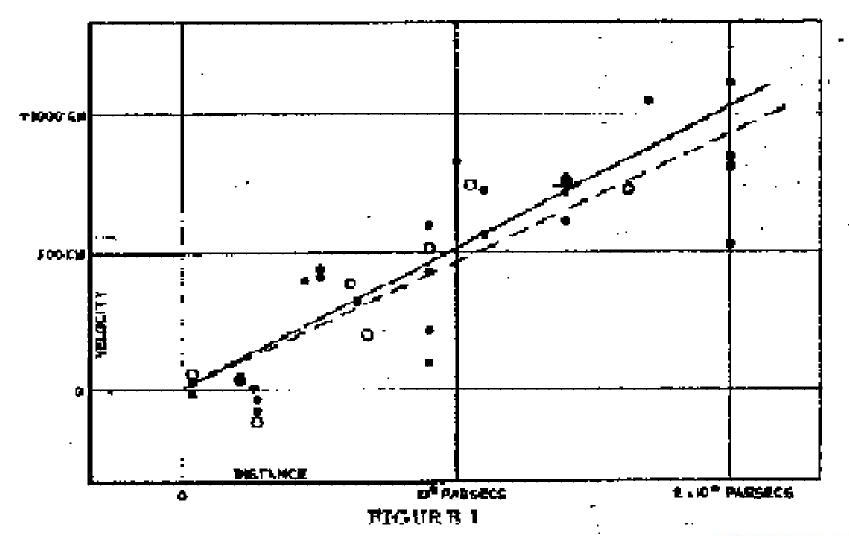








Hubble's Law

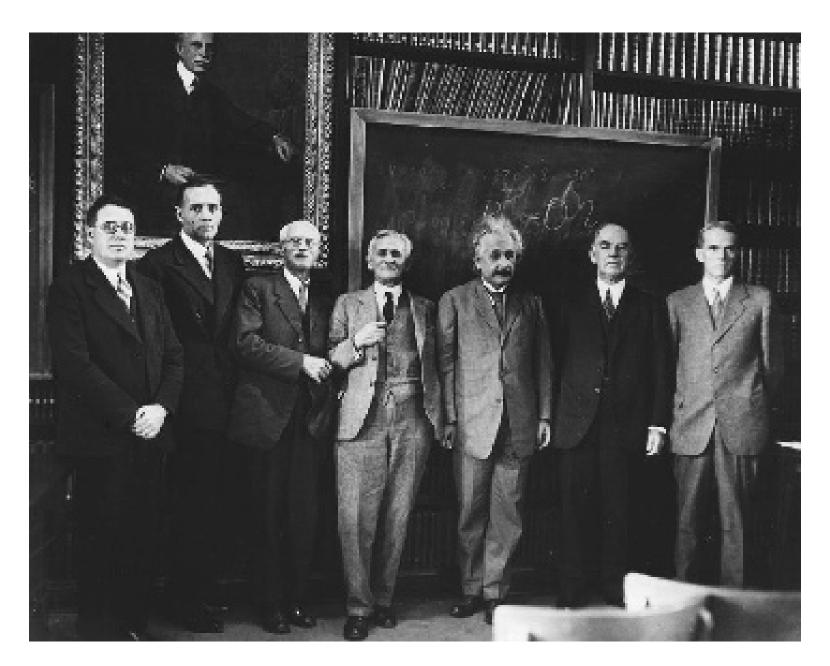








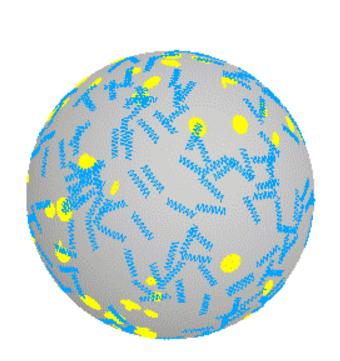


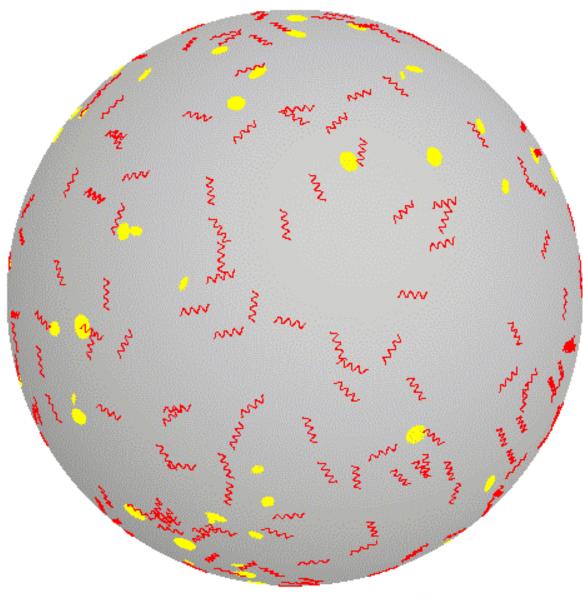














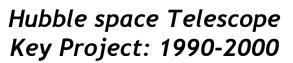






How fast is the Universe expanding?



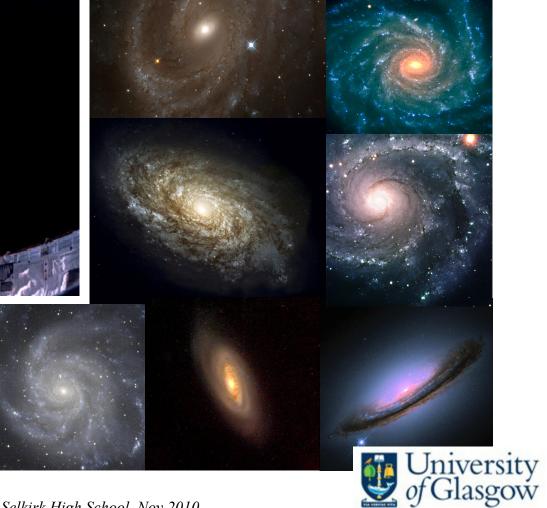


Cepheid distances to ~30 galaxies, linking to other standard candles

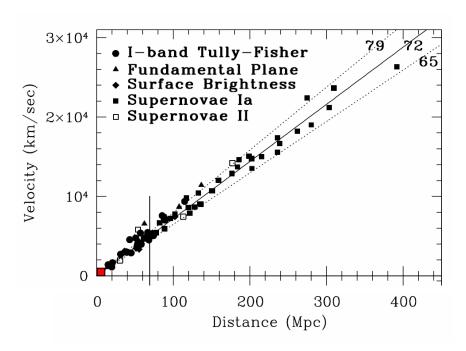








How fast is the Universe expanding?



Hubble space Telescope Key Project: 1990-2000

Cepheid distances to ~30 galaxies, linking to other standard candles

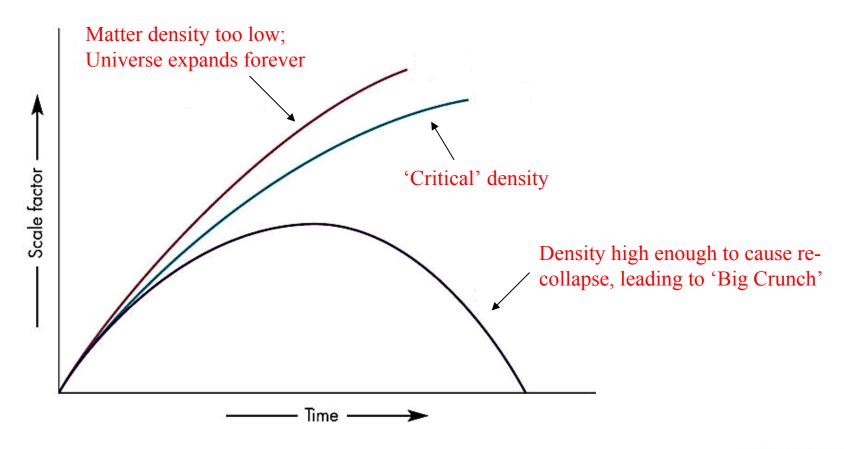






Will the Universe expand forever?

Answer depends on the amount of *matter* in the Universe.



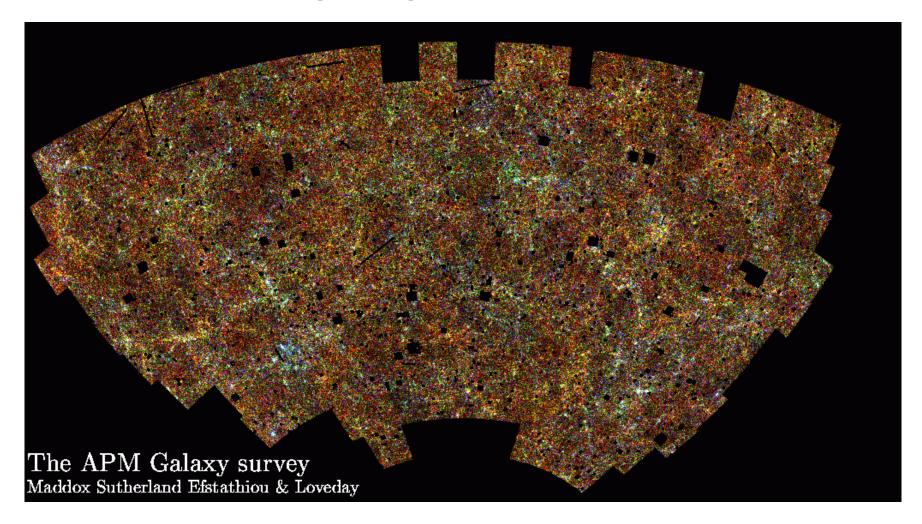








Weighing the Universe



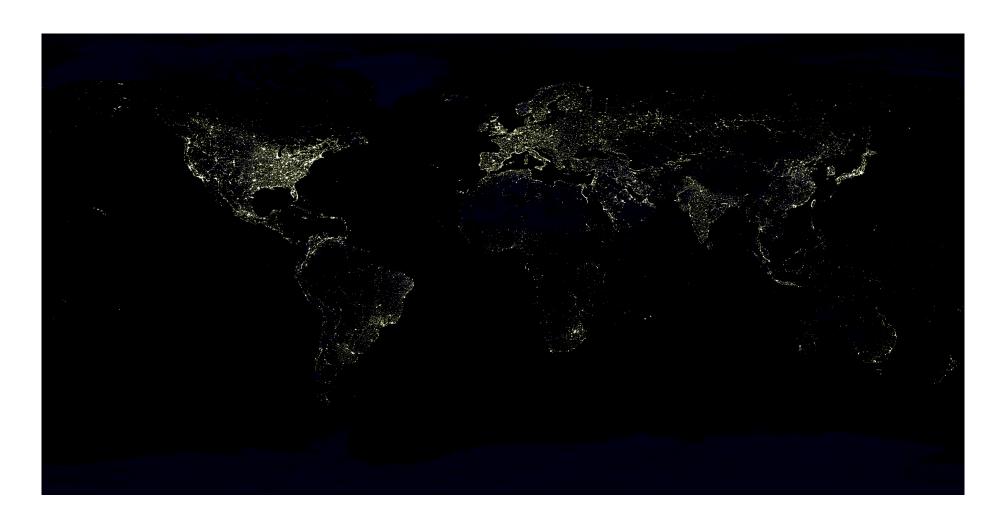








Weighing the Universe











National Course Specification: course details (Proposed Unit)

Higher Physics: Our Dynamic Universe

6.	The expanding Universe		
a)	The Doppler Effect and redshift of galaxies.	The Doppler Effect is observed in sound and light. For sound, the apparent change in frequency as a source moves towards or away from a stationary observer should be investigated. The Doppler Effect equations used for sound should not be used in the case of light from fast moving galaxies. This is because of relativistic effects. The redshift of a galaxy is the fractional difference between the observed wavelength and the wavelength that would be observed if the object were standing still. For closer galaxies redshift is the ratio of the velocity of the galaxy to the velocity of light.	Doppler Effect in terms of terrestrial sources e.g. passing ambulances. Investigating the apparent shift in frequency using a moving sound source and datalogger. Applications include measurement of speed (radar), echocardiogram and flow measurement.
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		matter. Measurements of the expansion rate of the Universe lead to the conclusion that the expansion rate is increasing, suggesting that there is something that overcomes the force of gravity – dark energy.	The history of how we learned the structure of the Milky Way, including its size and the average density of stars is a useful way to approach estimating the mass of a galaxy. This avoids reference to estimating mass using rates of rotation.
			The work of Einstein and in particular his description of his 'greatest blunder' is a useful way to explore the concept of dark energy.

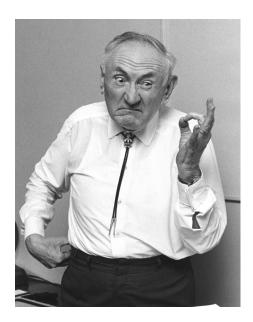






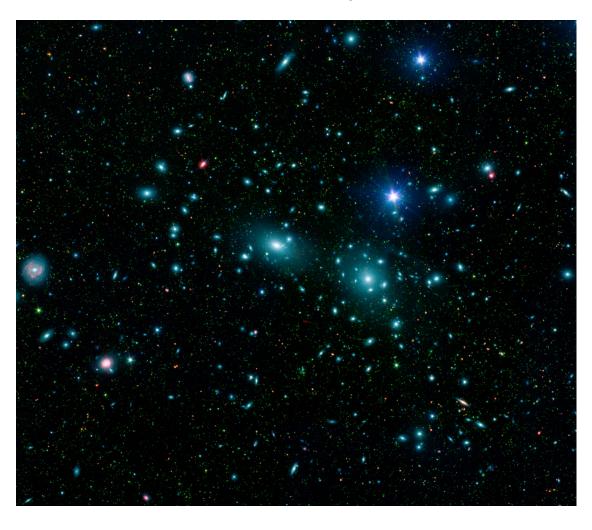


More than meets the eye?...



Fritz Zwicky

1933: finds evidence for **dark matter** in the Coma galaxy cluster











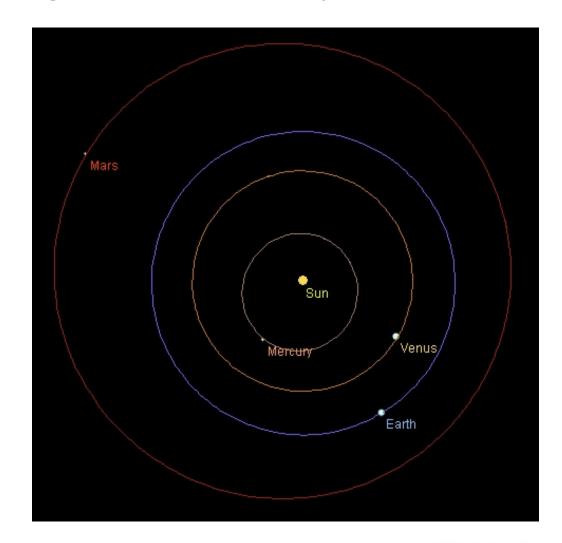
Weighing the Solar System



Johannes Kepler



Isaac Newton



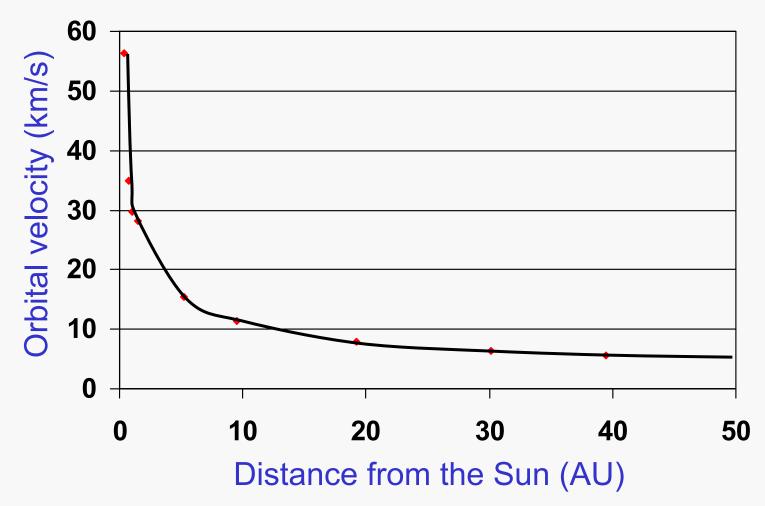








Weighing the Solar System











Weighing galaxies



Vera Rubin

1970s: studies the rotation curves of spiral galaxies, and finds that they are flat.









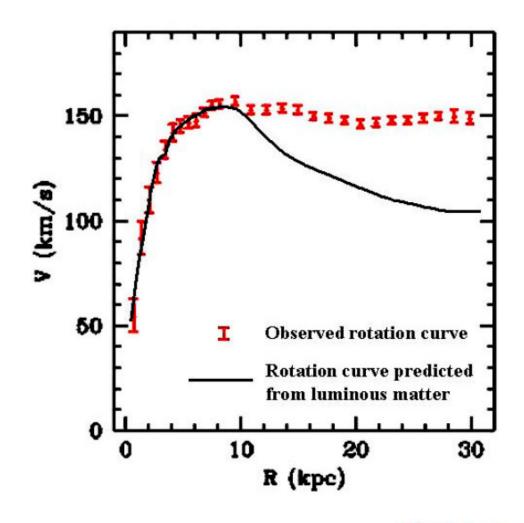


Weighing galaxies



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1970s: studies the rotation curves of spiral galaxies, and finds that they are flat.

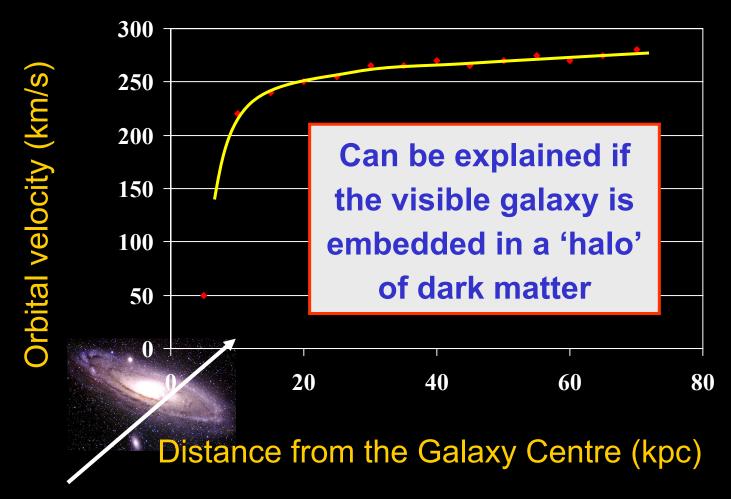




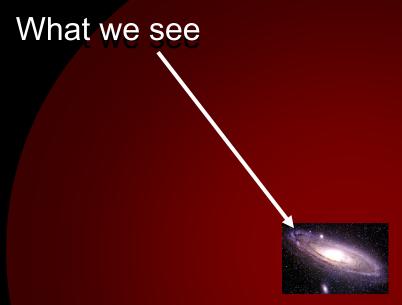








Typical size of galaxy disk



10 times as much as the luminous matter in the visible galaxy

What we think is really there....

National Course Specification: course details (Proposed Unit)

Higher Physics: Our Dynamic Universe

	•		
7)	Dia Dana Thaony		
7) Big Bang Theory			
a)	The temperature of space and stellar objects.	Thermal Radiation Spectra depend only on temperature. Hot objects emit light with a shorter wavelength. The emitted	Remote sensing of temperature. Investigating the temperature of hot objects using infrared sensors.
		power also depends on temperature. Thermal emission peaks allow the temperature of stellar objects to be measured.	
b)	Evidence for the Big Bang.	The Universe cools down as it expands. The peak wavelength of the measured cosmic microwave background corresponds to the theoretical peak predicted after the Big Bang.	History of Cosmic Microwave Background (CMB) discovery and measurement. Other evidence for the Big Bang includes the observed abundance of the elements hydrogen and helium and the darkness of the sky (Olber's Paradox).











1980s: Cosmic Cookery

Lightest elements made during first 3 minutes after the Big Bang...

$$p + n \longleftrightarrow d + \gamma$$

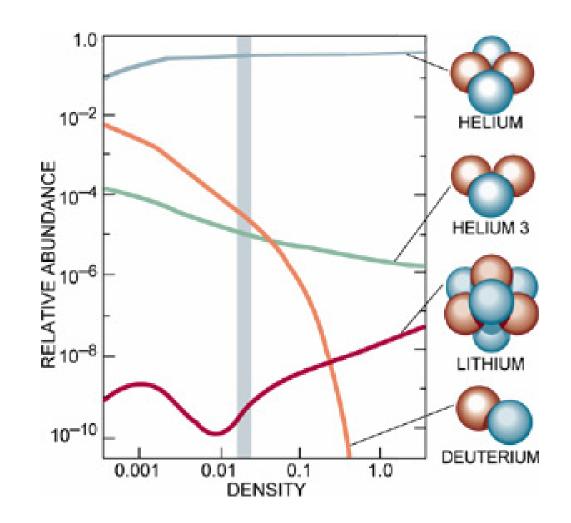
$$d + n \longrightarrow H^{3} + \gamma$$

$$H^{3} + p \longrightarrow He^{4} + \gamma$$

$$d + p \longrightarrow He^{3} + \gamma$$

$$He^{3} + n \longrightarrow He^{4} + \gamma$$

$$\vdots$$





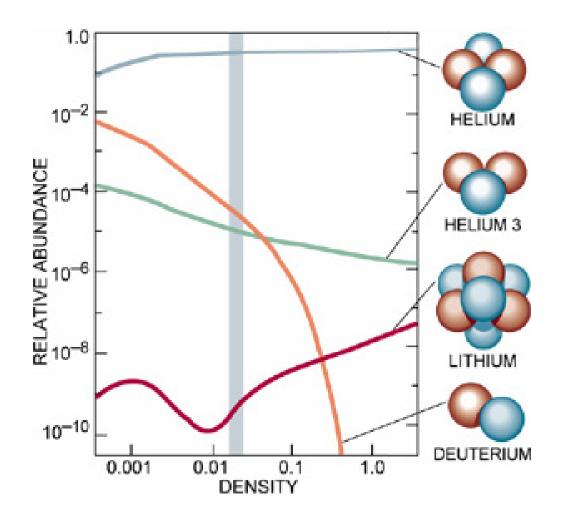






1980s: Cosmic Cookery

Amount of each element depends on the density of baryons.







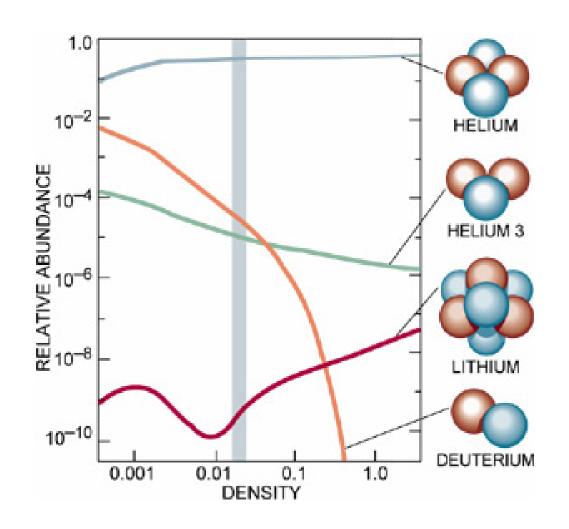




1980s: Cosmic Cookery

Amount of each element depends on the density of baryons.

Observed amounts match predictions very well, but *only* if baryons make up about 15% of all the dark matter.







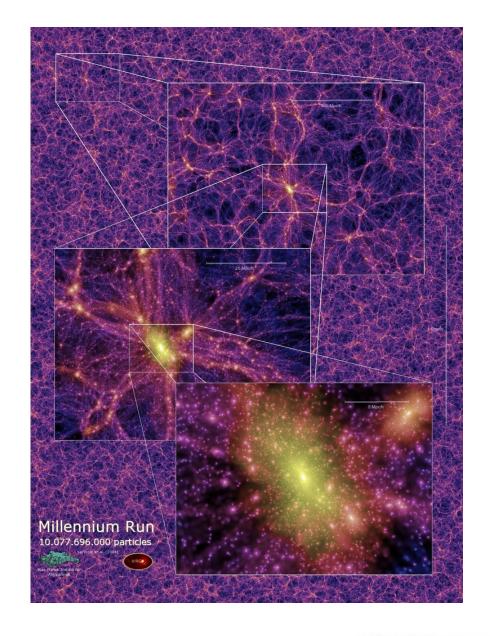




So what exactly *is* this dark matter?...

Computer models of galaxies tell us that it must be **cold** – i.e. not moving very fast.













So what exactly is this dark matter?...

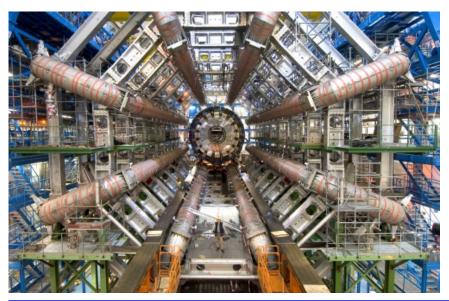
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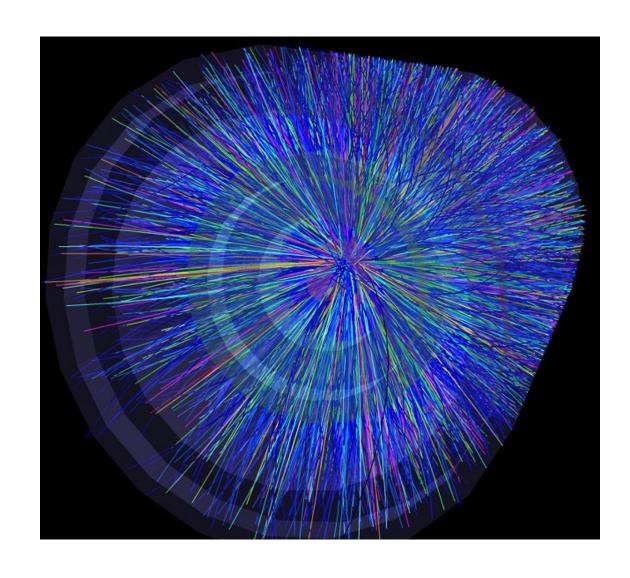




So what exactly *is* this dark matter?...

Computer models of galaxies tell us that it must be **cold** – i.e. not moving very fast.

Cold dark matter





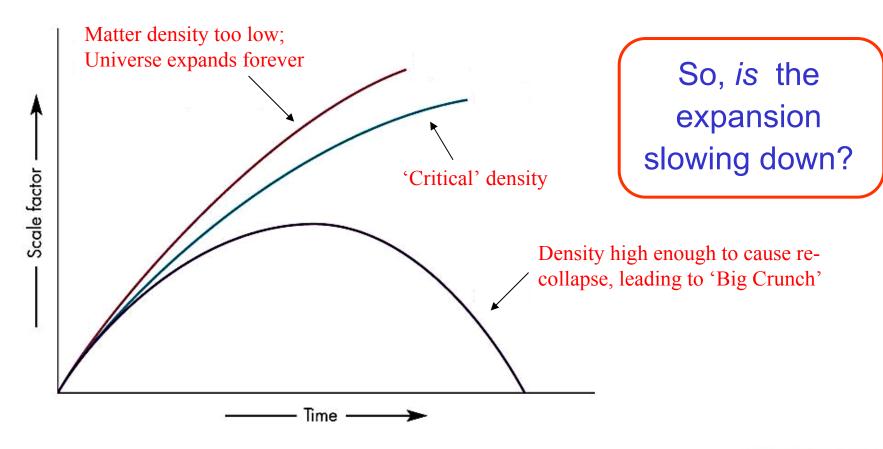






Will the Universe expand forever?

Answer depends on the amount of *matter* in the Universe.



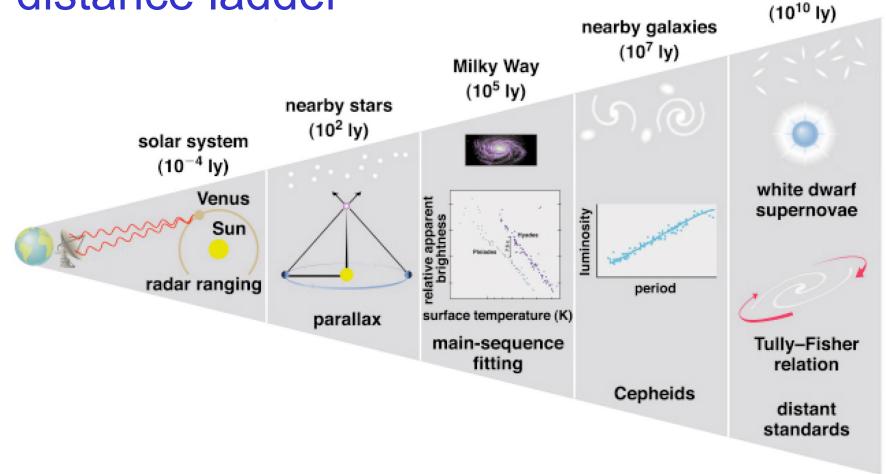








The Cosmic distance ladder





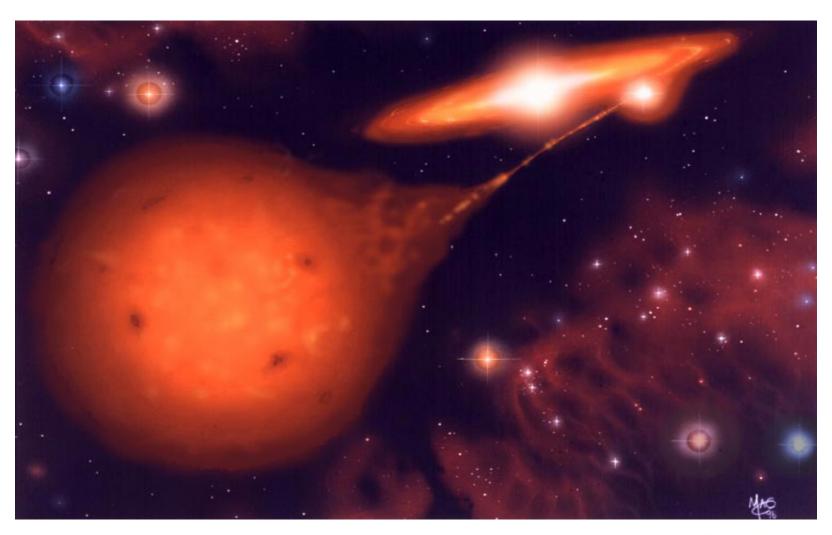






galaxy clusters

Is the Universe speeding up or slowing down?

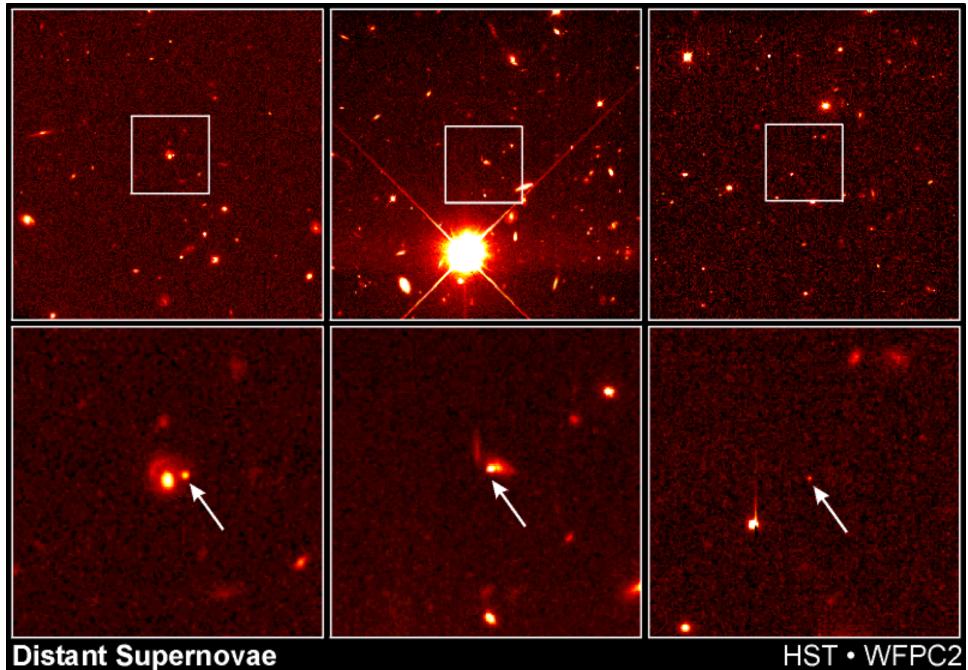






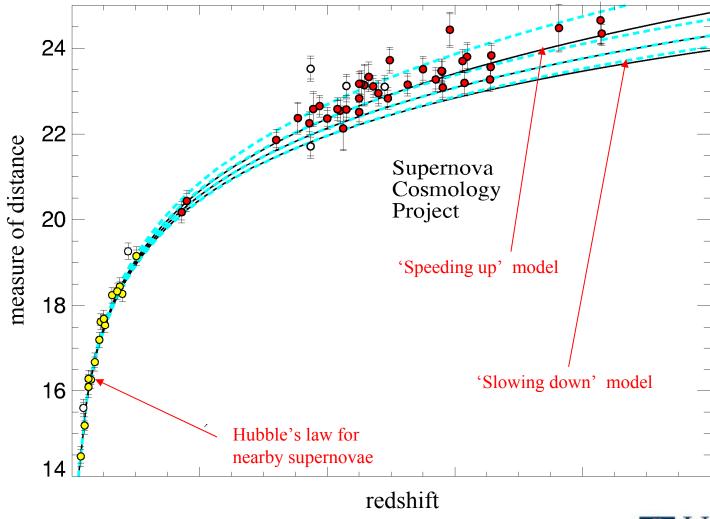






Distant Supernovae
PRC98-02 • January 8, 1998 • ST Scl OPO
P. Garnavich (Harvard-Smithsonian Center for Astrophysics) and NASA

Hubble diagram of distant supernovae

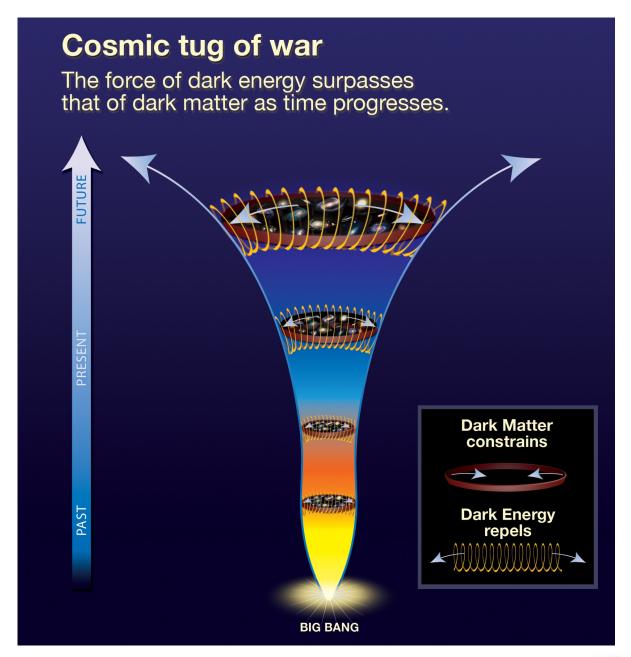










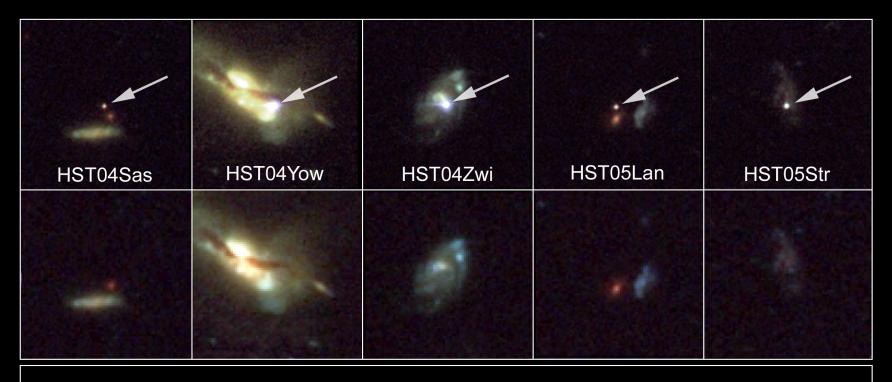












Host Galaxies of Distant Supernovae Hubble Space Telescope • Advanced Camera for Surveys

NASA, ESA, and A. Riess (STScI)

STScI-PRC06-52

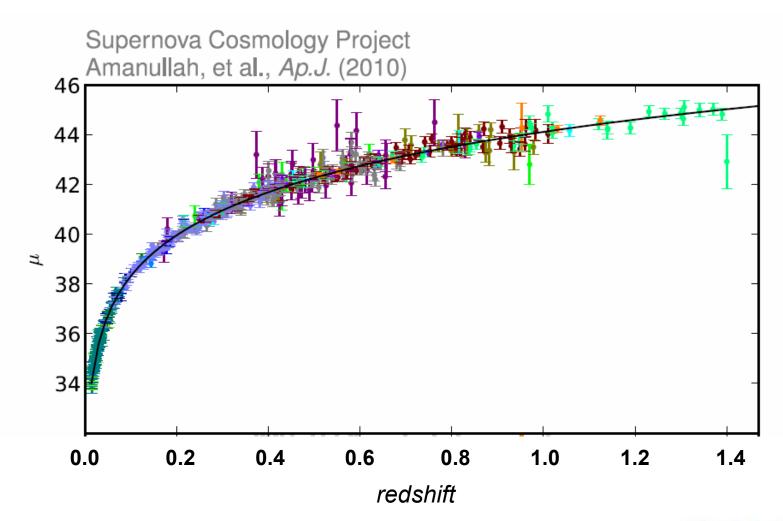








Latest results: still speeding up!!!











The future of the Universe?

No

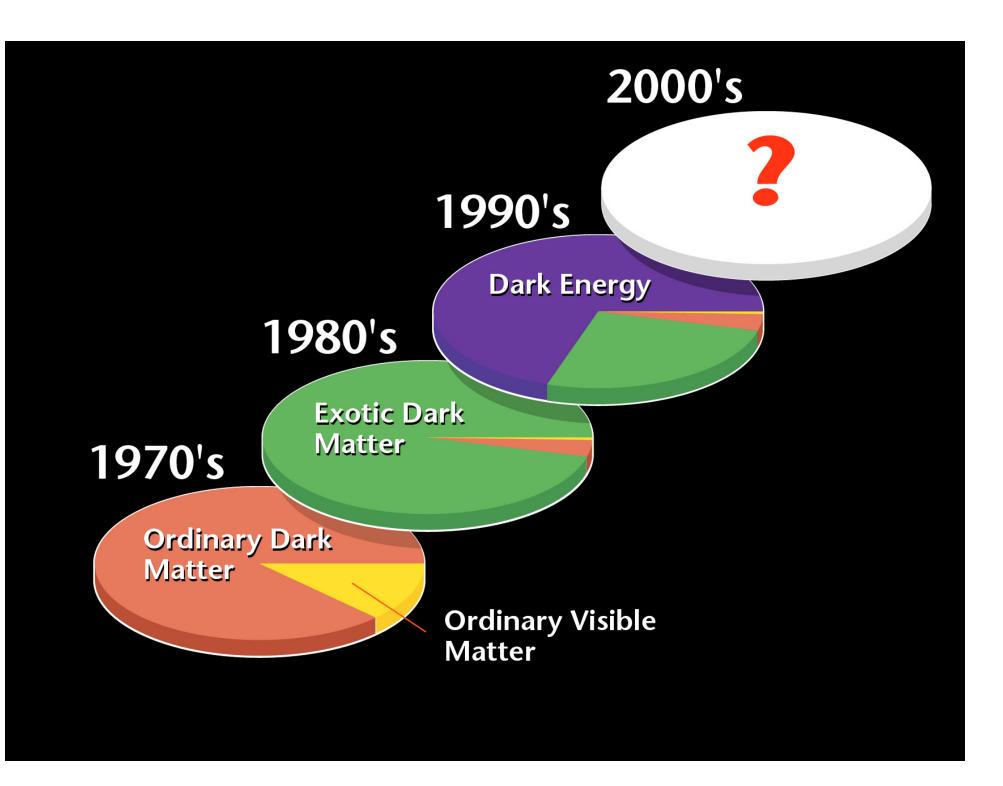
Big Crunch!!!











National Course Specification: course details (Proposed Unit)

Higher Physics: Our Dynamic Universe

	•		
7)	Dia Dana Thaony		
7) Big Bang Theory			
a)	The temperature of space and stellar objects.	Thermal Radiation Spectra depend only on temperature. Hot objects emit light with a shorter wavelength. The emitted	Remote sensing of temperature. Investigating the temperature of hot objects using infrared sensors.
		power also depends on temperature. Thermal emission peaks allow the temperature of stellar objects to be measured.	
b)	Evidence for the Big Bang.	The Universe cools down as it expands. The peak wavelength of the measured cosmic microwave background corresponds to the theoretical peak predicted after the Big Bang.	History of Cosmic Microwave Background (CMB) discovery and measurement. Other evidence for the Big Bang includes the observed abundance of the elements hydrogen and helium and the darkness of the sky (Olber's Paradox).











The Background Radiation

Since 2003, measurements of the Cosmic Background Radiation have helped to convince us that the Universe really is accelerating, and dominated by dark energy.

CBR = relic radiation from the Big Bang itself.

Appears to us like a 'bank of fog'





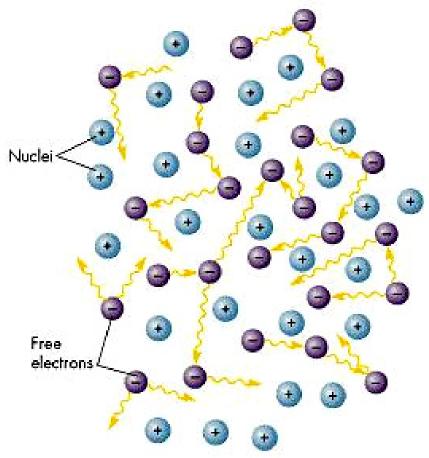






Early Universe too hot for neutral atoms to exist

Free electrons scatter light (as in a fog)







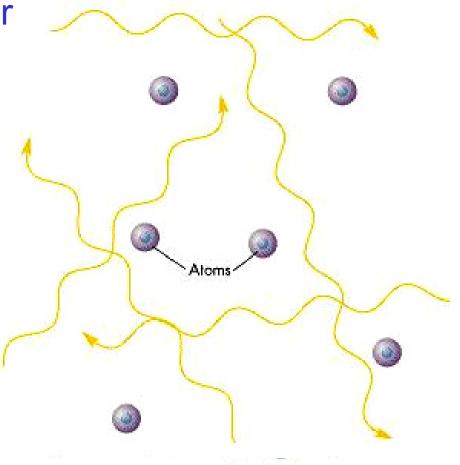




Early Universe too hot for neutral atoms to exist

Free electrons scatter light (as in a fog)

After ~380,000 years, Universe cool enough for neutral hydrogen to form: the fog clears!









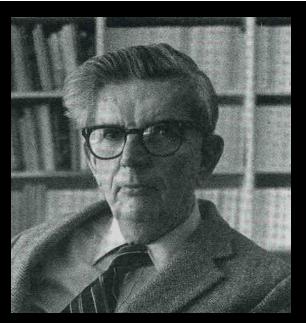


Background radiation predicted in 1950s and 1960s by Gamov, Dicke, Peebles.

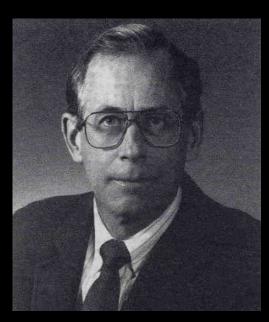
Discovered in 1965 by Penzias and Wilson



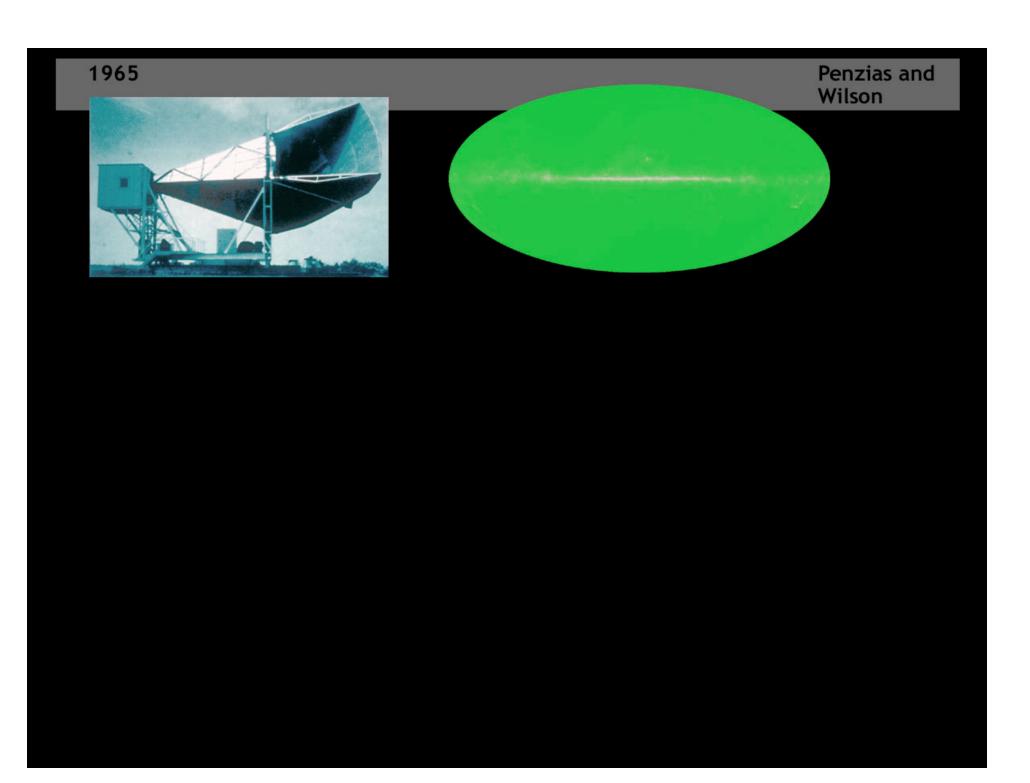
Arno Penzias and Robert Wilson

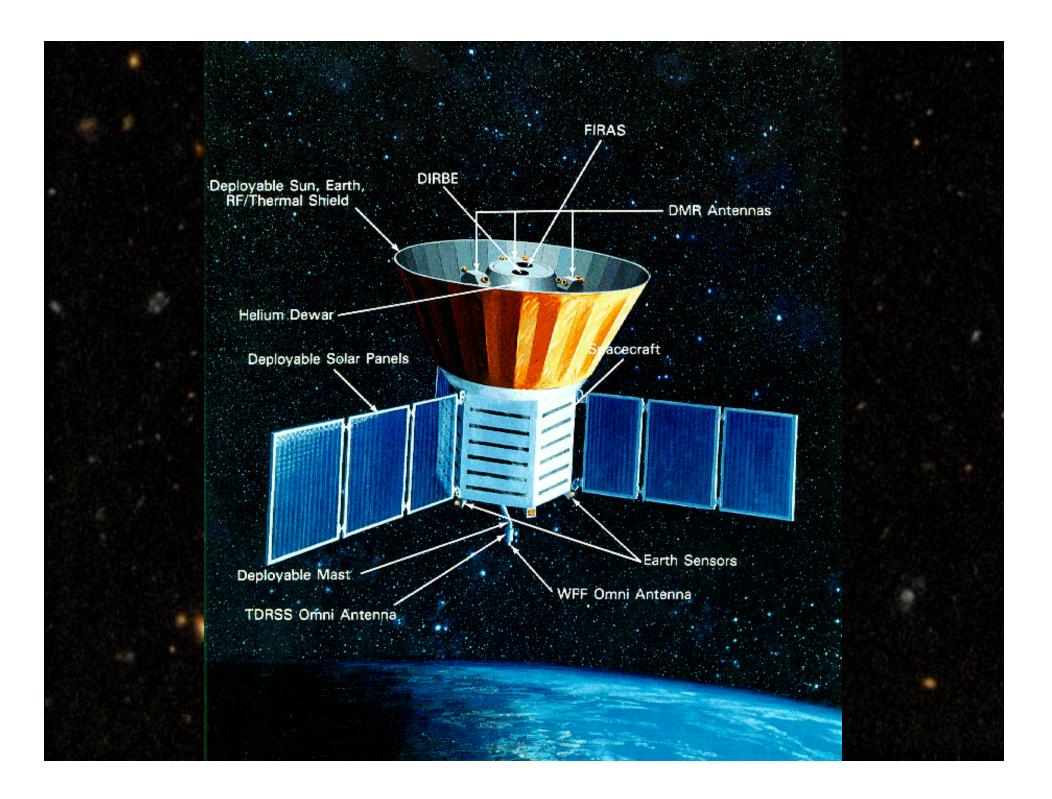


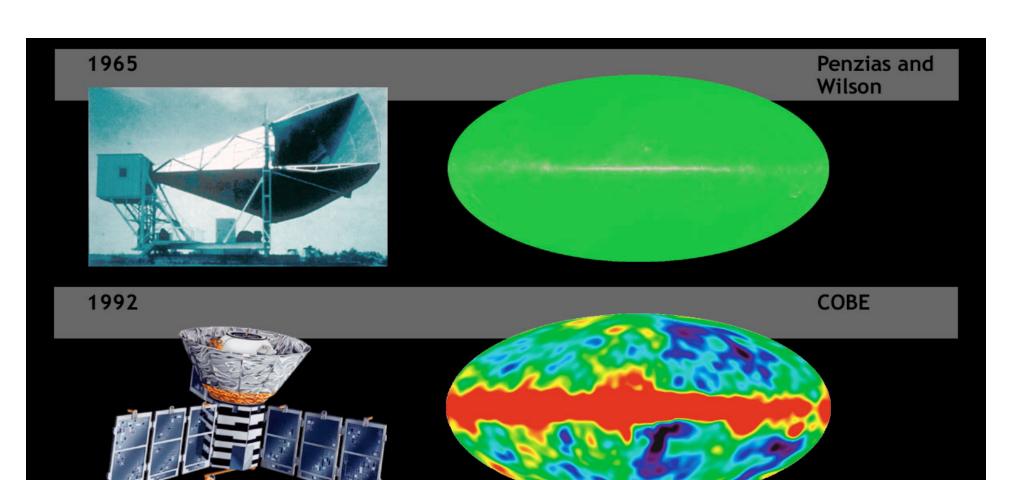
Robert Dicke



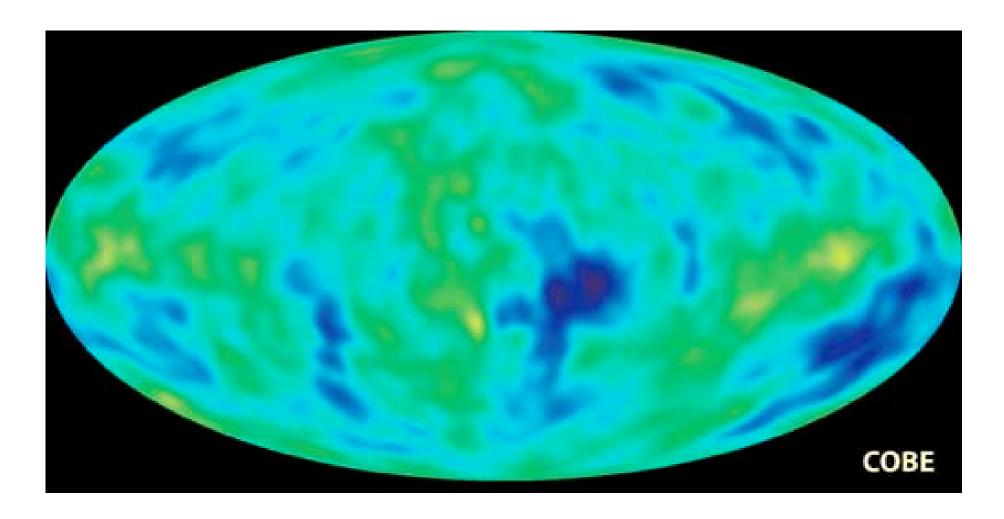
Jim Peebles







COBE map of temperature across the sky

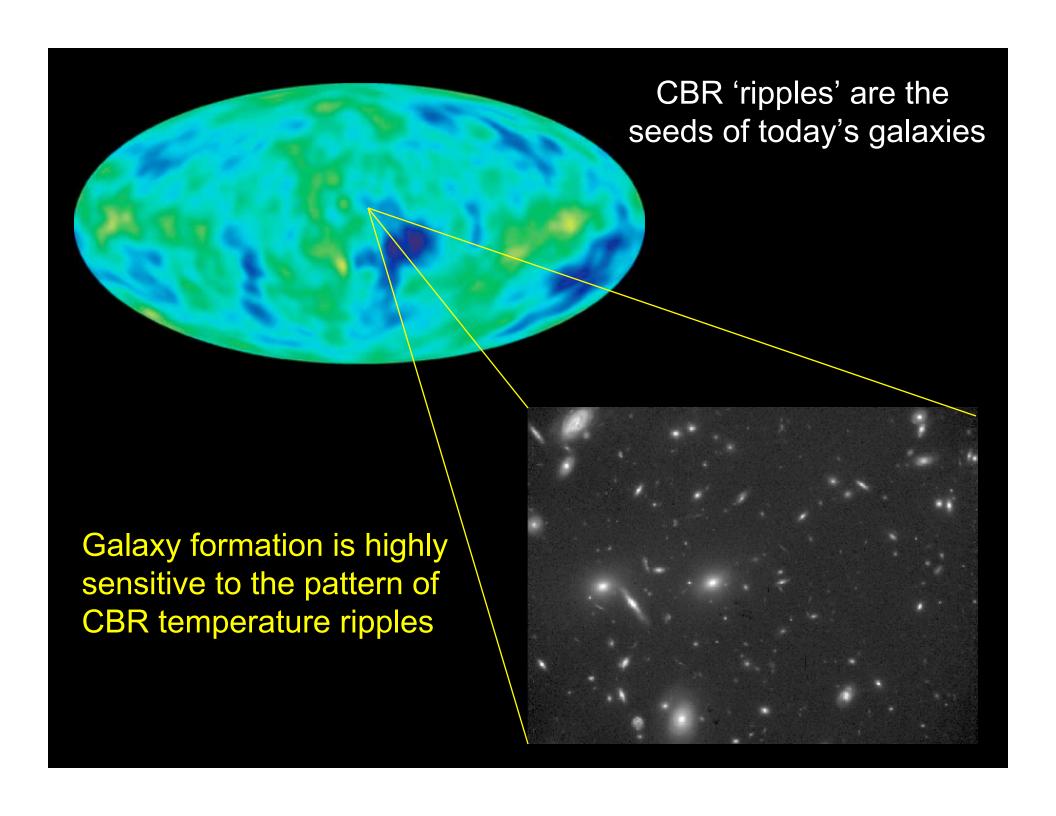


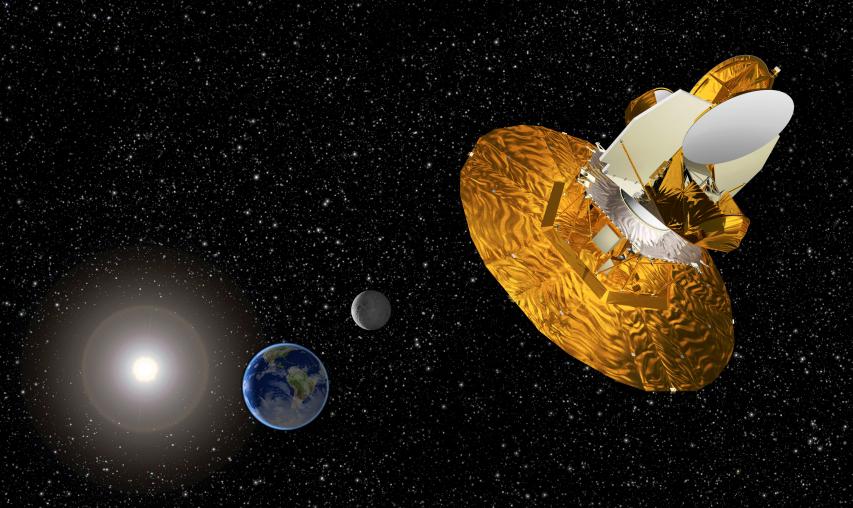


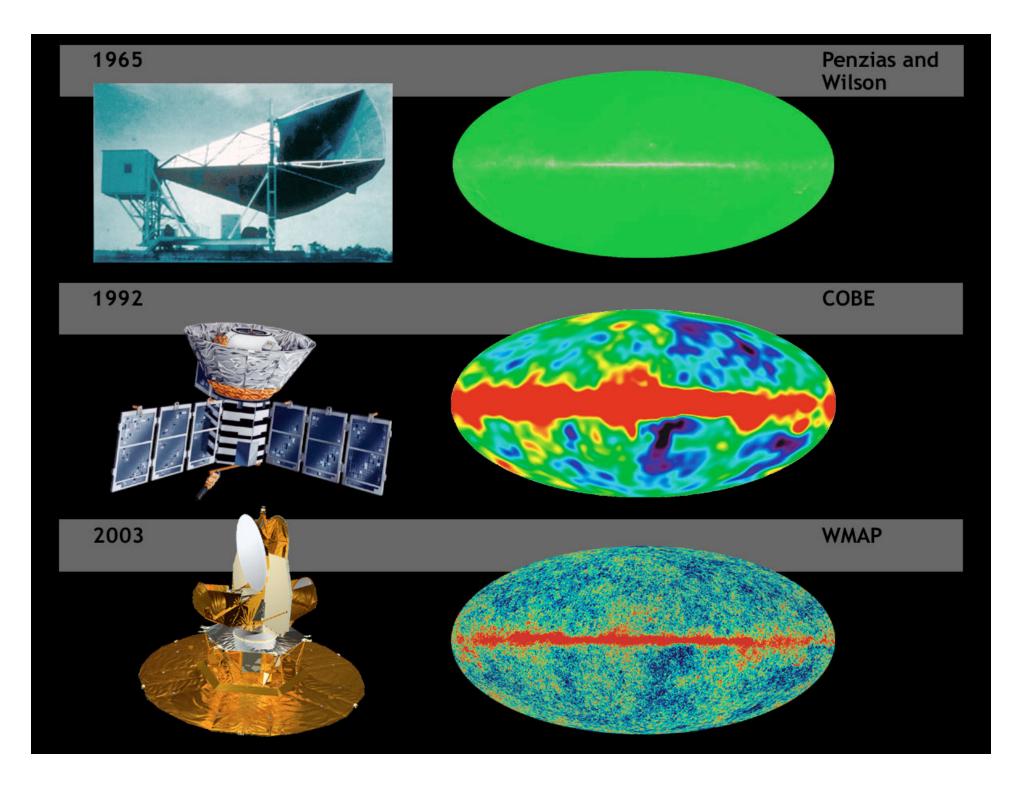




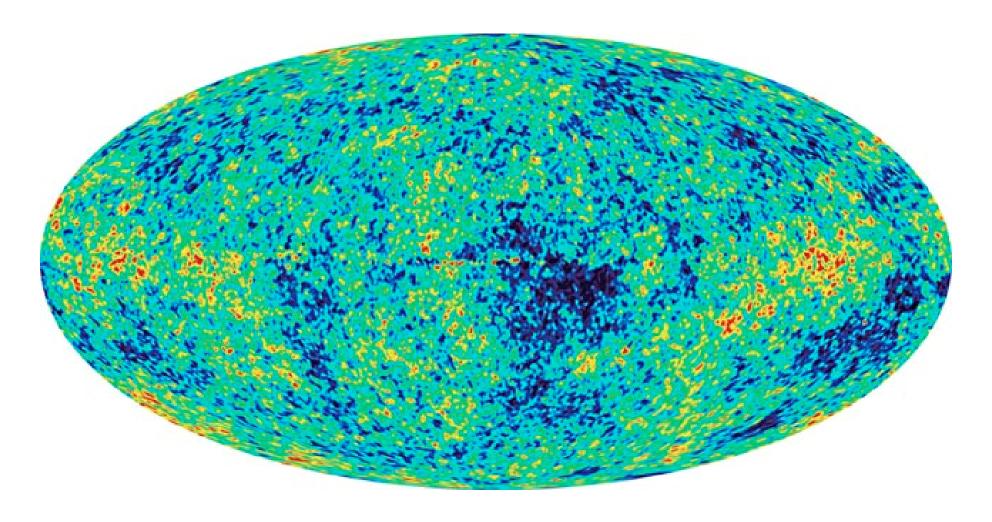








WMAP map of temperature across the sky

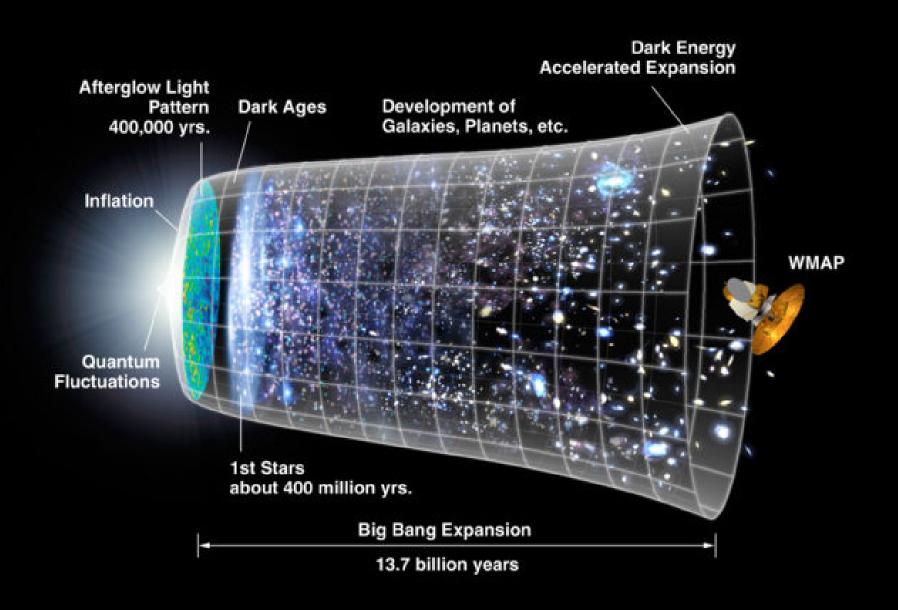




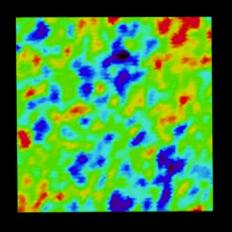


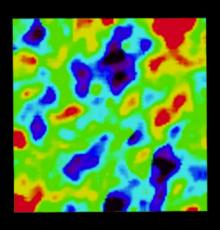


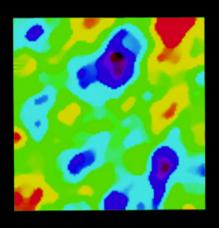


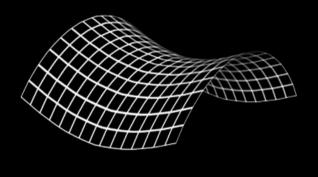


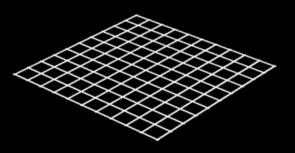
GEOMETRY OF THE UNIVERSE

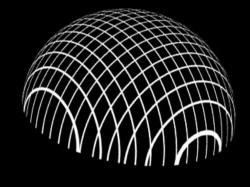








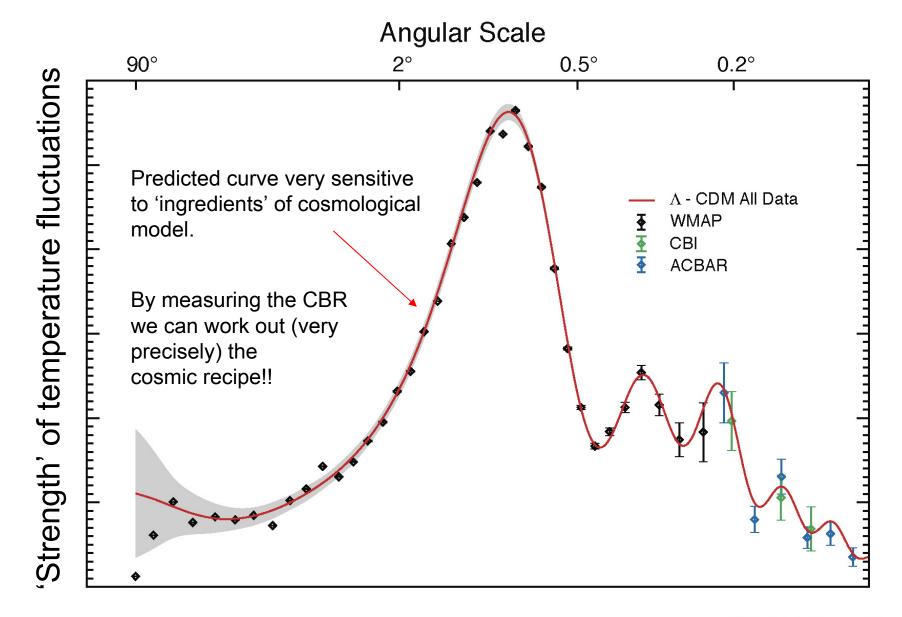




OPEN

FLAT

CLOSED











The future of cosmology?...



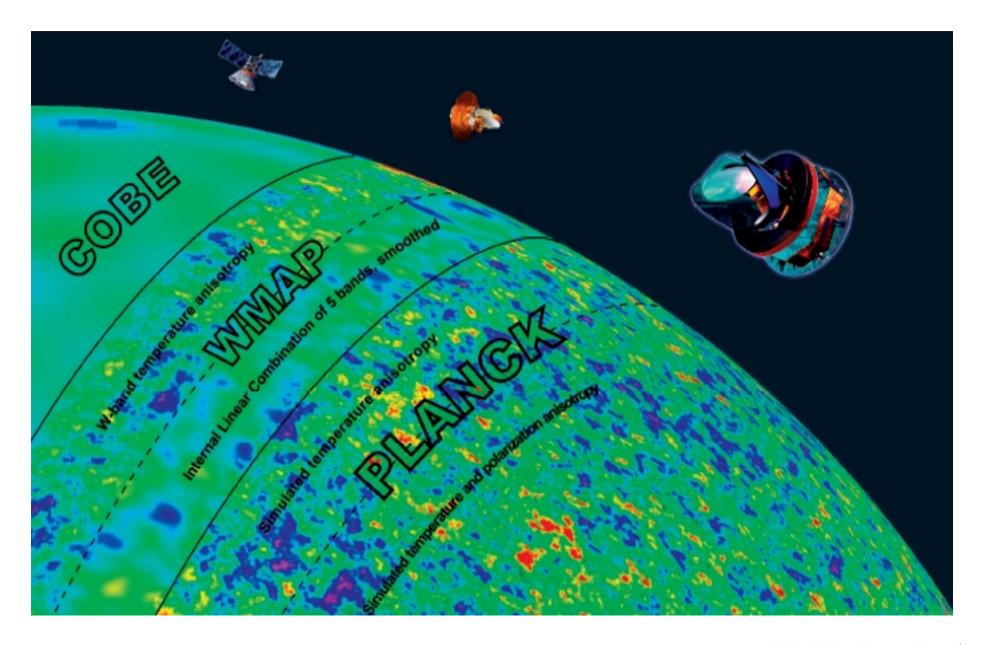












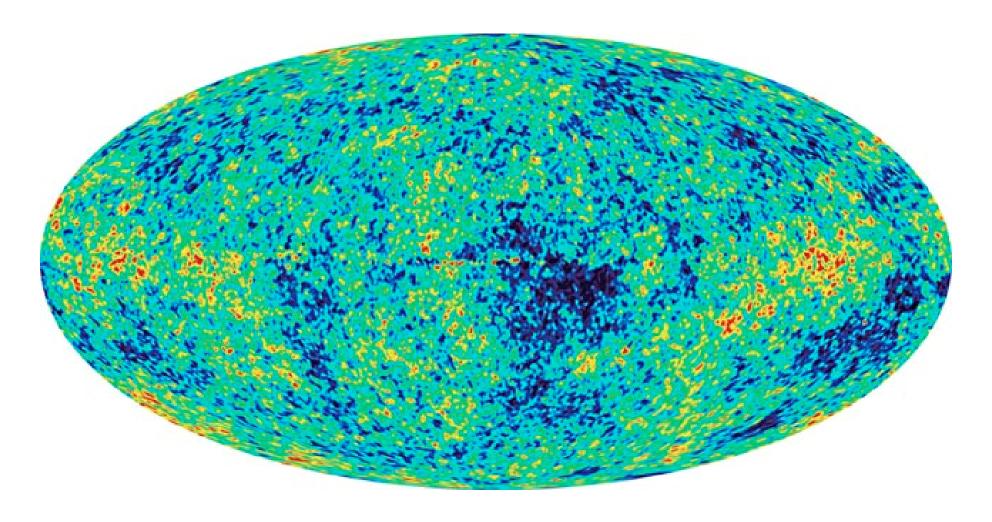








WMAP map of temperature across the sky



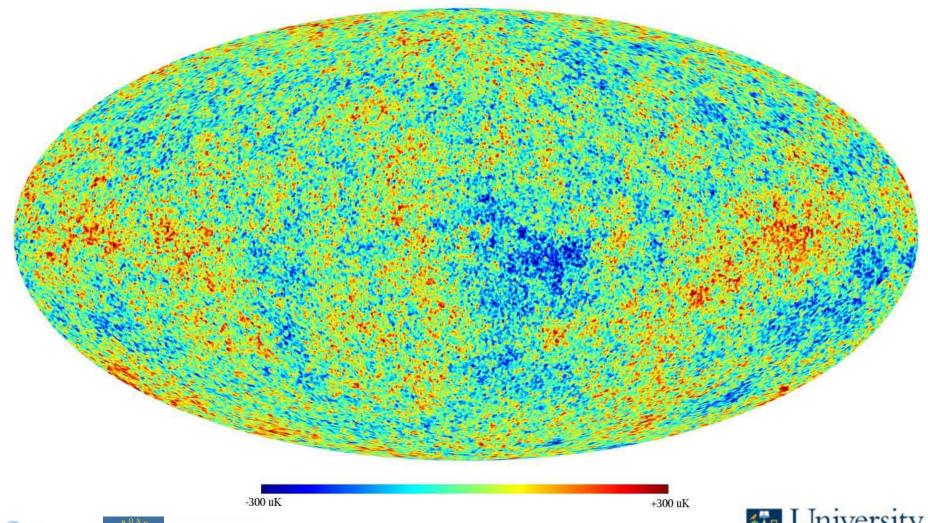








Simulated Planck temperature map











So how do we build current research into the new Physics curriculum?...

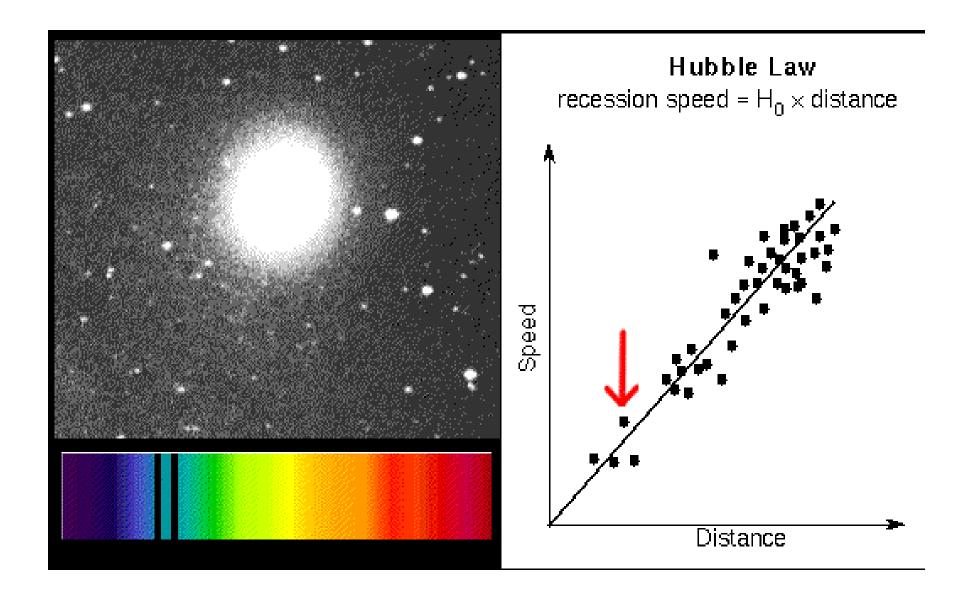
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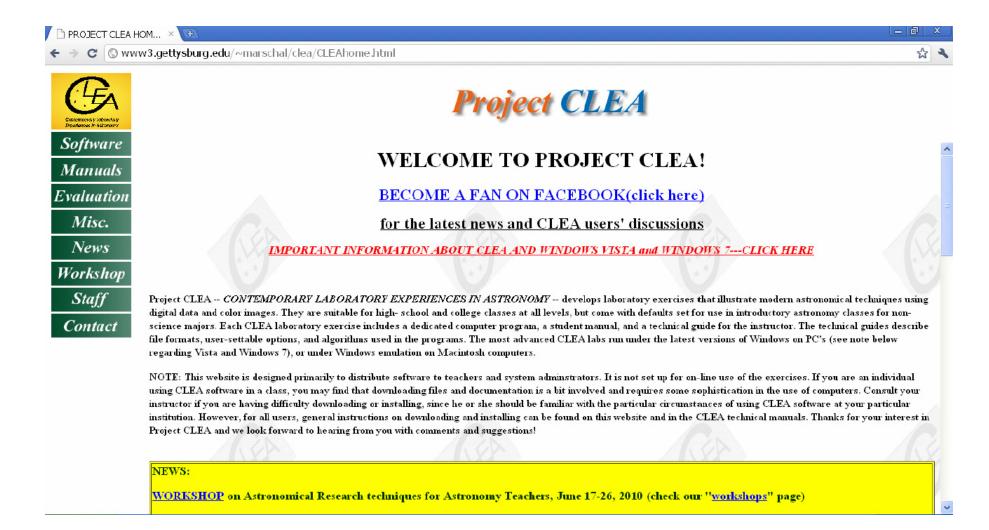








Project CLEA: Contemporary Laboratory Experiences in Astronomy

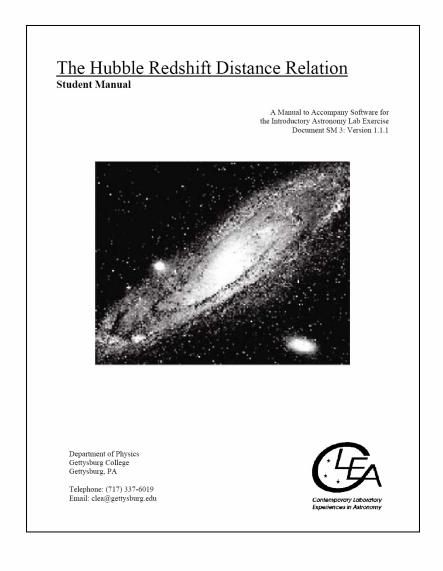


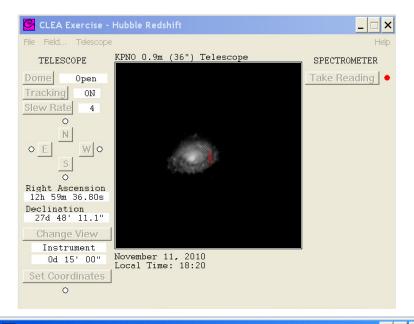


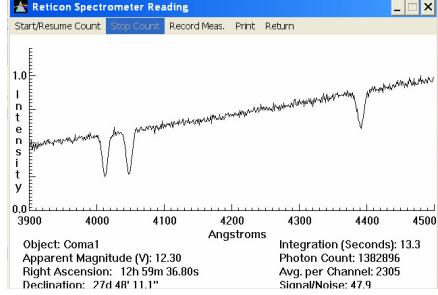










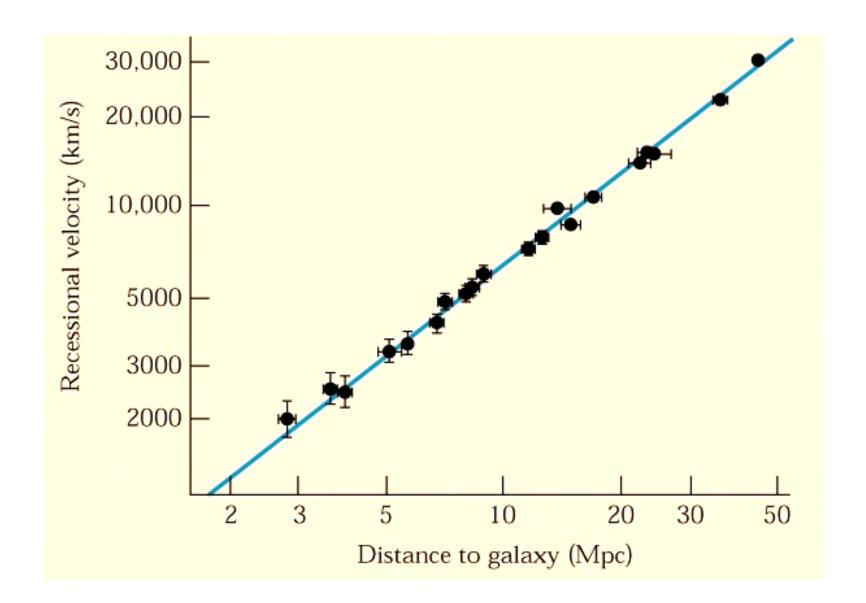




















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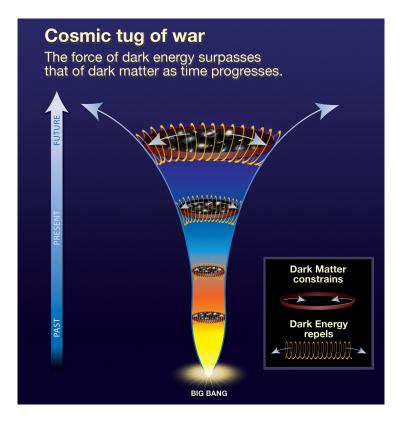
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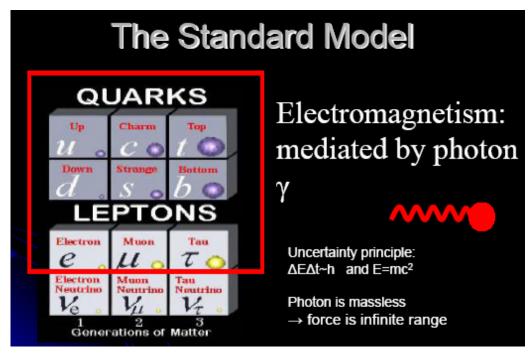














"All science is either physics or stamp collecting"

Ernest Rutherford









National Course Specification: course details (Proposed Unit)

Higher Physics: Our Dynamic Universe

4. Gravitation		
a) Projectiles and Satellites.	Resolving the motion of a projectile with an initial velocity into horizontal and vertical components and their use in calculations. Comparison of projectiles with objects in free fall. Newton's thought experiment and an explanation of why satellites remain in orbit.	Using software to analyse videos of projectiles Low orbit and geostationary satellites. Satellite communication and surveying. Environmental monitoring of the conditions of the atmosphere.
b) Gravity and mass.	Gravitational Field Strength of planets, natural satellites and stellar objects. Calculating the force exerted on objects placed in a gravity field. Newton's Universal Law of Gravitation.	Methods for measuring the gravitational field strength on Earth. Using the slingshot effect to travel in space. Lunar and planetary orbits. Formation of the solar system by the aggregation of matter. Stellar formation and collapse. The status of our knowledge of gravity as a force may be explored. The other fundamental forces have been linked but there is as yet no unifying theory to link them to gravity.
5. Special relativity		
a) Introduction to special relativity.	Relativity introduced through Galilean Invariance, Newtonian Relativity and the concept of absolute space. Experimental and theoretical considerations (details not required) leads to the conclusion that the speed of light is the same for all observers. The constancy of the speed of light led Einstein to postulate that space and time for a moving object are changed relative to a stationary observer. Length contraction and time dilation. Using the time dilation and length contraction equations although no derivation is required.	Newtonian Relativity can be experienced in an intuitive way. Examples include walking in a moving trains and moving sound sources. At high speeds, non-intuitive relativistic effects are observed. Length contraction and time dilation can be studied using suitable animations. Experimental verification includes muon detection at the surface of the Earth and accurate time measurements on airborne clocks. The time dilation equation can easily be derived from the geometrical consideration of a light beam moving relative to a stationary observer.









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- North Ayrshire
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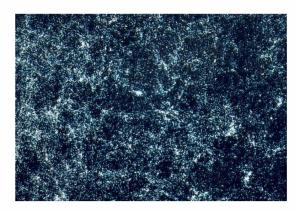




<u>Large Scale Structure of the Universe</u>

Student Manual

A Manual to Accompany Software for the Introductory Astronomy Lab Exercise Document SM 7: Circ. Version 1.1.1



Department of Physics Gettysburg College Gettysburg, PA

Telephone: (717) 337-6019 Email: clea@gettysburg.edu

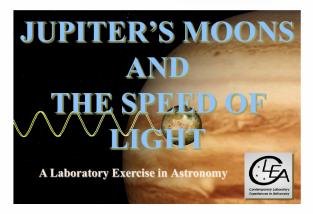


Jupiter's Moons and the Speed of Light

JUPITER'S MOONS AND THE SPEED OF LIGHT

Student Manual

A Manual to Accompany Software for the Introductory Astronomy Lab Exercise Document SM 15: Circ.Version 1.0



Department of Physics Gettysburg College Gettysburg, PA 17325 Telephone: (717) 337-6028 email: clea@gettysburg.edu

Database, Software, and Manuals prepared by:
Jan Paul Dabrowski, Marylhurst University, Glenn Snyder and Laurence
Marschall (Project CLEA, Gettysburg College)

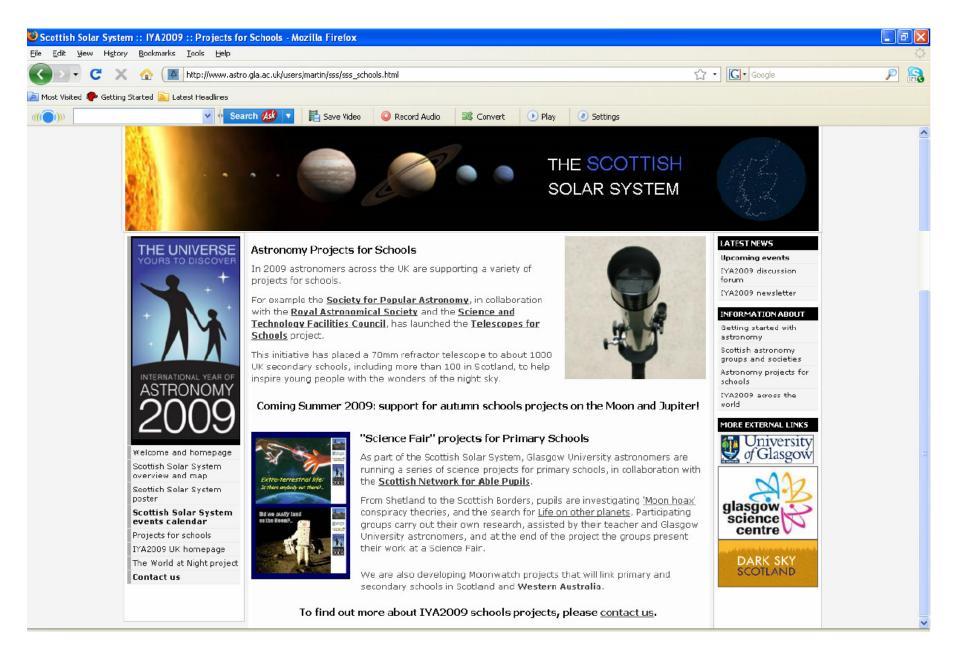






















International Year of Astronomy 2009

Schools Projects for Autumn Moonwatch

Project 4: The Moons of Jupiter

Suitable for advanced primary and secondary ages, and for telescopic observing.

One of the most important of Galileo's discoveries was the four moons of the planet Jupiter. These are still known today as the Galilean satellites and they are: (in order of increasing distance from Jupiter) lo, Europa, Ganymede and Callisto.

In recent years we have come to know these four worlds in fantastic detail, thanks to the Voyager and Galileo spacecraft which visited them. In 1610 through Galileo's telescope, however, they appeared simply as points of light – like little stars accompanying Jupiter across the sky. Nonetheless, Galileo's discovery was remarkable: for the first time there was clear evidence that celestial bodies did *not* orbit the Earth. This was a crucial step towards establishing that the Earth was *not* at the centre of the Universe.

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Fig 1: Extract from Galileo's diary, January 1610, showing the changing positions of the four moons of Jupiter

During the autumn and winter evenings of 2009-10 Jupiter and its moons are well placed for observing through binoculars or a small telescope. Over the course of a few nights, you will see the moons change their position as they orbit the giant planet – sometimes crossing the disk in front, sometimes disappearing behind it.

The orbit of Io, the closest Galilean moon, lies at roughly the same distance from Jupiter as our Moon does from the Earth. And yet, because Jupiter is more than 300 times more massive than the Earth, its gravity whips Io around in its orbit once every 42 hours.





















MOONWATCH WEEKS

from the Society for Popular Astronomy

HOME

ABOUT THE MOON

SCHOOLS' TELESCOPE

MOONWATCH

courtesy U. S. N. O.



First quarter Moon

About the Moonwatch Weeks 2009

Put these dates in your diary!



Mare Crisium

MoonWatch weeks

Spring MoonWatch 28 March - 5 April

Autumn MoonWatch 24 October - 1 November

Schools MoonWatch 19 - 29 November

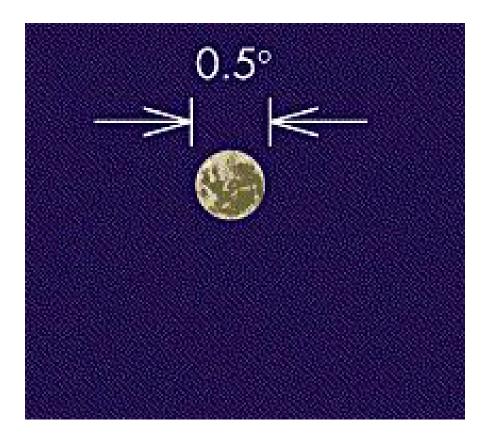




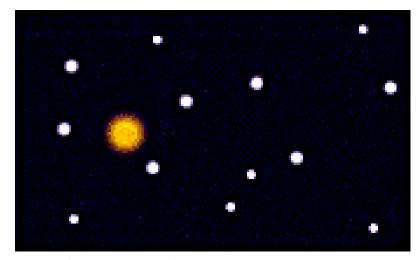




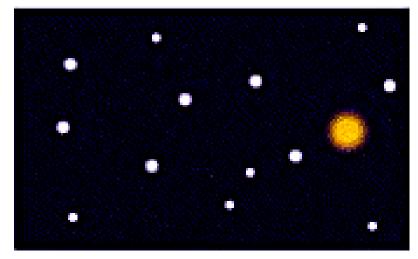
Parallax Shift



Even the nearest star shows a parallax shift of only 1/2000th the width of the full Moon



View from the Earth in January



View from the Earth in July









The Moon as seen from Perth, Scotland 6pm local time, on 30th November 2009

Electra

Angle between the Moon's centre and Electra = 11.25 degrees

The Moon as seen from Perth, Western Australia 2am local time, on 1st December 2009

Electra

Angle between the Moon's centre and Electra = 12 degrees

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- East Dunbartonshire
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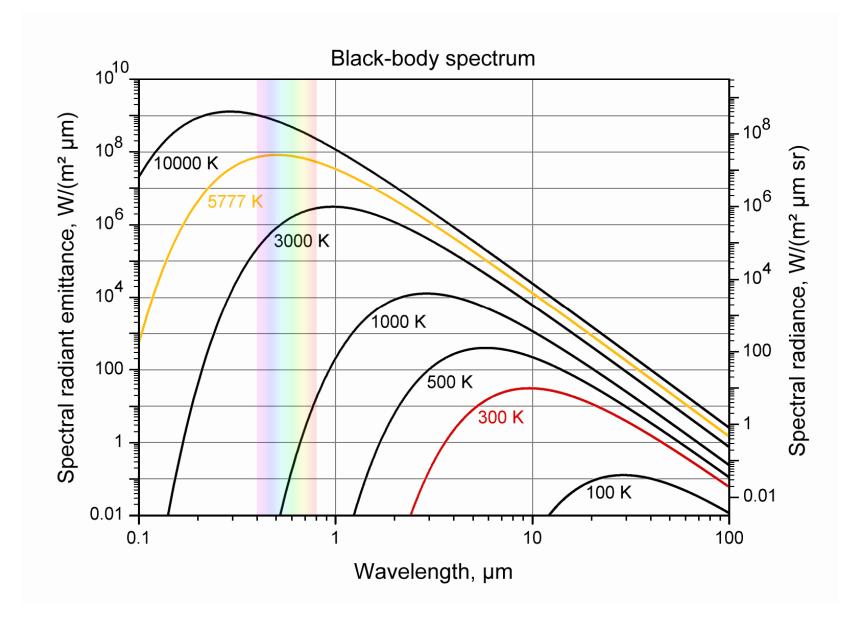










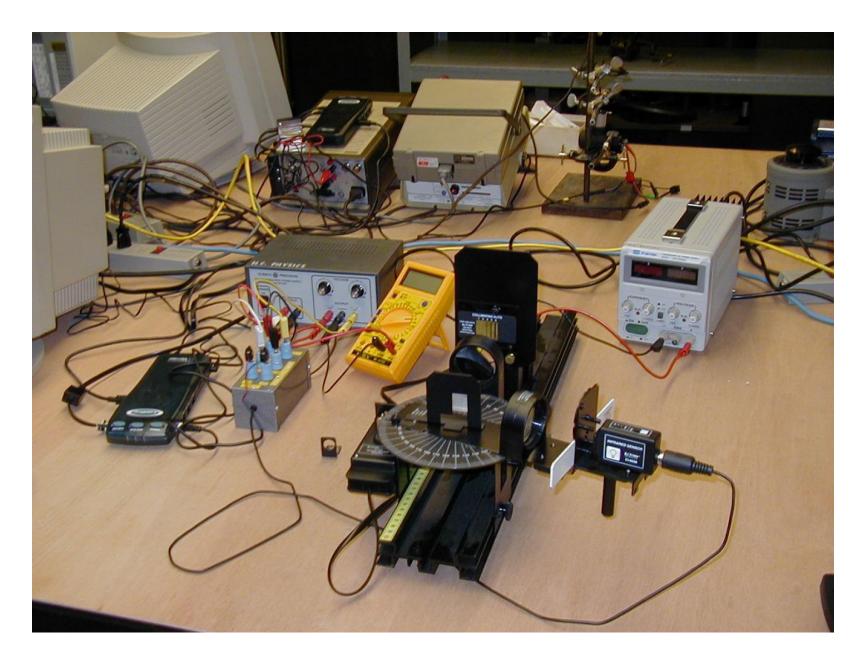










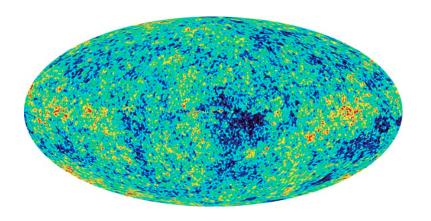


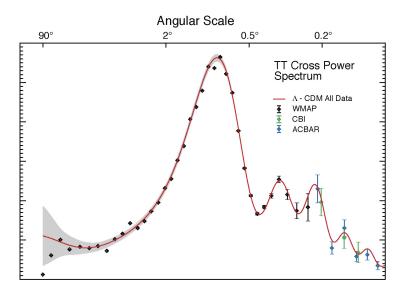












"What fraction of the cars in the car park are red?..."











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STEMNET creates opportunities

to inspire young people in science, technology, engineering and maths Log in

search website





STEM Ambassadors



"Science and technology are increasingly vital in the world today and the study of these subjects benefits all of us whether we realise it or not. Scientists like me have a very important role to play in inspiring the next generation to see these areas as exciting — both through sharing experiences and offering young people the chance to get involved in practical work in a real-life scientific environment."

Lord Professor Robert Winston, a supporter of STEMNET's Ambassadors programme

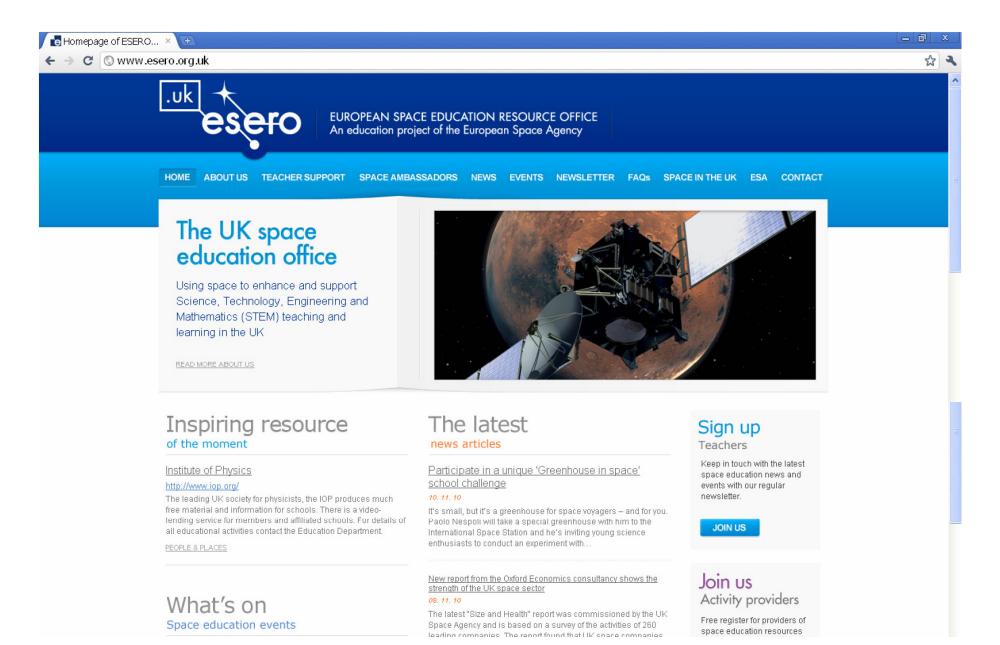




































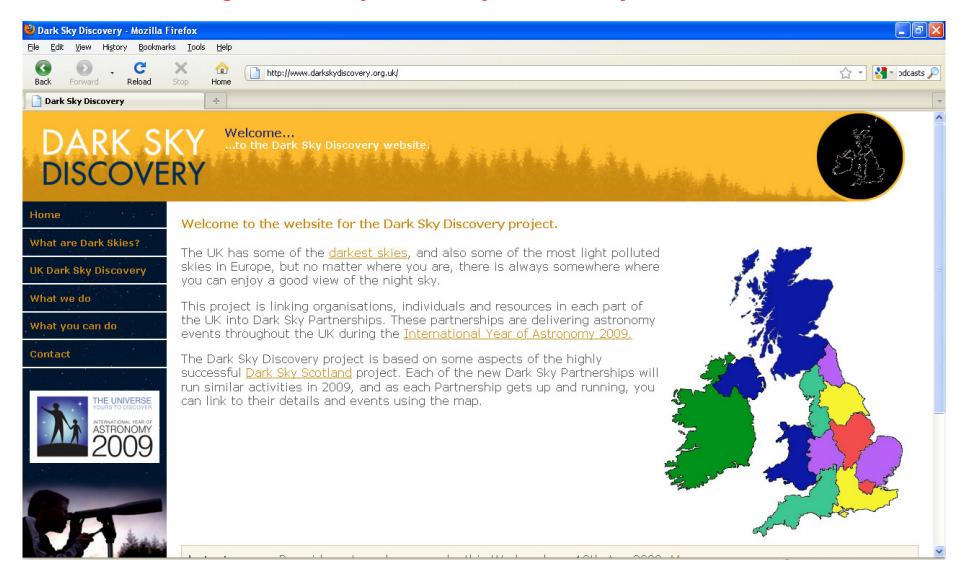








Linking to Dark Sky Discovery Community-based events



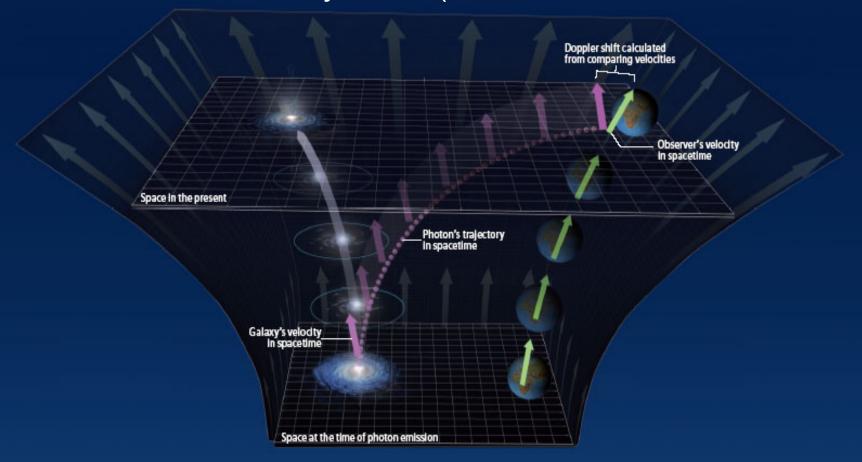








Scientific American, July 2010. (Tamara Davis, UQueensland)



GALAXY REDSHIFT AS A DOPPLER SHIFT

A galaxy's redshift is identical to the Doppler shift an observer would see when watching a police car recede at the same relative velocity as the galaxy—as long as "relative velocity" is interpreted in the appropriate way. First, one must trace the trajectories of the galaxy and of the observer not in space but in spacetime. (In the schematic view here, space is an evolving two-dimensional surface; spacetime trajectories cut through it.) Second, one must compare the velocity of the galaxy at the time when it

emitted the photon (*purple arrow*) with the velocity of the observer at the time when the photon was received (*green arrow*) and then—using the appropriate math derived from general relativity—calculate the relative velocity. The Doppler shift calculated from this relative velocity coincides with the galaxy's redshift, suggesting that the galaxy's redshift can be interpreted as the result of relative motion, rather than of the expansion of space. Therefore, no energy is lost.

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The Physics of Star Wars Reality or fantasy?

Imagine that some of your pupils have just watched the latest sci-fi release, and come to ask you about the 'real physics' content of the film.

Some examples of the questions they might ask are given below. Choose a few of these questions and think about how you would you answer them. Could you relate your answers to accepted physical ides and principles?...



Spaceships

- > How could we travel faster-than -light?
- Could a spaceship have a hyperspace drive, or warp drive?



Weapons

- How would a light sabre work?
- > Could the Death Star destroy a planet?

Planets

- Could life exist on a planet with two suns?
- Could life exist on a planet with a giant sun?











Summary

- Lots of interesting topics in cosmology & astrophysics
- Focussing on process, rather than just latest results and facts, broadens scope for simple but instructive experiments and research exercises:

Mixture of practical and computer-based, (mostly) with minimal equipment costs.

 Lots of help available, e.g. Universities, Astrosocs (Industry?). Tailored resources being developed.

Watch this space!...







