

Galaxies and Beyond



Origin of the Milky Way, Tintoretto



Peter Watson, Dept. of Physics

The Size of the Universe



*We come spinning out of nothingness,
scattering stars like dust.* Rumi



Peter Watson

A little Time-Travelling

How should you
be dressed?
Like Lady Caroline



A TEXT-BOOK
OF
GENERAL ASTRONOMY
FOR
COLLEGES AND SCIENTIFIC SCHOOLS
BY
CHARLES A. YOUNG, PH.D., LL.D.,
PROFESSOR OF ASTRONOMY IN THE COLLEGE OF NEW JERSEY
(PRINCETON).
BOSTON, U.S.A., AND LONDON:
GINN & COMPANY, PUBLISHERS.
1889.

The question at once arises whether clusters, such as the one mentioned in Hercules, are composed of stars each comparable with our sun....., or whether the bodies which compose the swarm are really very small,----whether the distance of the mass from us is about the same as that of the stars among which it seems to be set, or whether it is far beyond them. Forty years ago the accepted view was that the stars composing the clusters are no smaller than ordinary stars, and that the distance of the star-clusters is immensely greater than that of the isolated stars. There are many eloquent passages in the writings of that period based upon the belief that these star-clusters are,---"galaxies," like the group of stars to which the writers supposed the sun to belong, but so inconceivably remote that in appearance they shrank to these mere balls of shining dust.

It is now, however, quite certain that the other view is correct,---that star-clusters are among our stars and form part of our universe.



Peter Watson



HST picture



Peter Watson

Age of the Solar System. Looking backward, then, in imagination we see the sun growing continually larger through the reversed course of time, expanding and becoming ever less and less dense, until at some epoch in the past it filled all the space now included within the largest orbit of the solar system.

How long ago that was no one can say with certainty. If we could assumethat all the heat radiated has come from this source only, without subsidy from any original store of heat contained in an original "firemist" then it is not difficult to conclude that the sun's past history must cover some 15,000,000 or 20,000,000 years.

Actually 4,500,000,000 years:
Remember we don't have $E = mc^2$

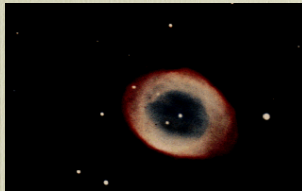
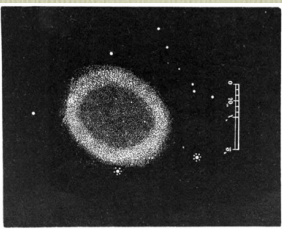


Peter Watson

Distance of the Nebulae---On this point we have very little absolute knowledge. ..Still it is probable, indeed almost certain, that they are at the same order of distance as the stars. The wisps of nebosity which photography shows attached to the stars in the Pleiades ... and numerous nebulae which have a star exactly in the centre,---these compel us to believe that in such cases the nebosity is really at the star.



- M57 (Ring Nebula) clearly associated with star, hence at same distance as stars.



Peter Watson

Distance of the Nebulae-

Fifty years ago a very different view prevailed. .. astronomers at that time very generally believed that there was no distinction between nebulae and star-clusters except in regard to distance...They considered a nebula, therefore, as a "universe of stars" like our own "galactic cluster" to which the sun belongs, but as far beyond the "star-clusters" as these were believed to be beyond the isolated stars. *In some respects this old belief strikes one as grander than the truth even. It made our vision penetrate more deeply into space than we now dare think it can.*

- Can't see star in M31 (Great nebula in Andromeda)

must be at least many thousand times the area of Neptune's orbit.



Can't resolve individual stars until mid 20th century
Actually *many billions times the area of Neptunes orbit!*



Peter Watson

Structure of the Heavens.

The great mass of the stars which compose this (stellar) system are spread out on all sides in or near a widely extended plane, passing through the Milky Way. ... having the form of a round, flat disc, the diameter of which is eight or ten times its thickness....Our sun is near the centre of this disc-like space.

As to the distance of the remotest stars in the stellar system, it is impossible to say anything very definite, but it seems quite certain that it must be at least so great that light would occupy from 10,000 to 20,000 years in traversing it. If one asks what is beyond the stellar system, whether the star-filled space extends indefinitely or not, no certain answer can be given.

The Milky Way

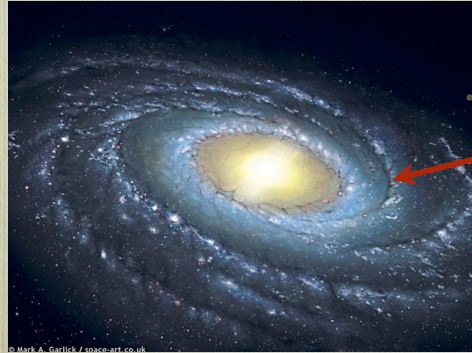
- This is the Milky way, showing the whole sky



Peter Watson

The Milky Way is hard to see, since we are inside it!

- But it looks roughly like this
- With the sun about here



Peter Watson

One thing Prof. Young didn't know about

Black Holes

Peter Watson

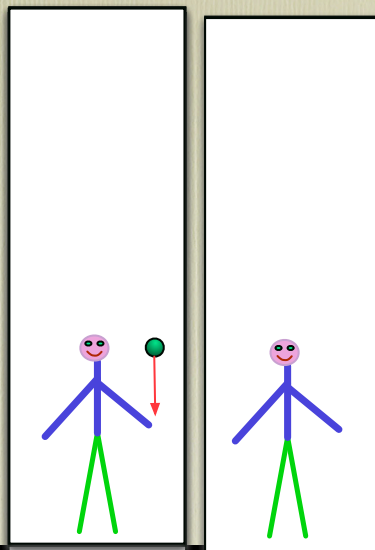
Black Holes

Invented by

- Einstein
- Hawking?
- Schwarzschild?
- None of the above?
- Well, actually, **John Michell**, rector of Thornhill Church in Yorkshire
- geologist? philosopher? astronomer? Seismologist? Polymath.
- presented his ideas to the Royal Society in London in 1783.

Peter Watson

- A particle will escape from the earth if it has positive energy
- At the earth's surface, "escape velocity" is 11 km/s



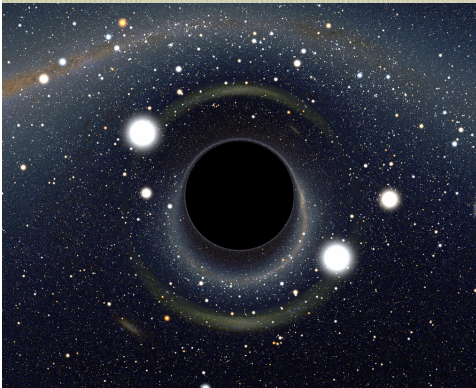
Peter Watson

- If we throw it back
- Throw it
- But if it goes nothing
- If the earth



Peter Watson

- One way to see a black hole: it's black!
- If we are really lucky...(or unlucky) as a gap in the sky



Note multiple images of same star

Alain Riazuelo, IAP/UPMC/CNRS

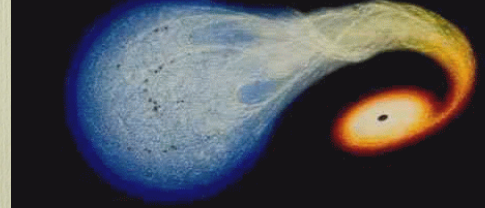
Peter Watson

- Stuff falling in will become very hot and produce X-rays
- Cygnus X-1: visible star ~20 mass of sun
- Invisible object $M \sim 9M_{\odot}$
- Power output in X-rays is 10,000 x total power output by sun!

Cygnus X-1 black hole

C2

© 1993 Loch Ness Productions
markspet@icision.alphacdc.com
Artist: Tim M. Kuzmar



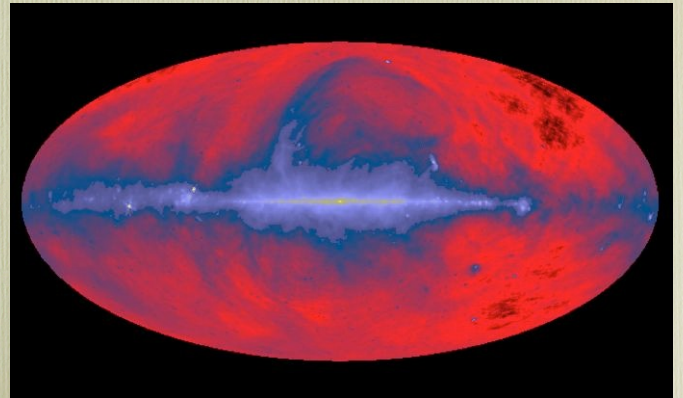
But there are much bigger black holes around



- This is the Milky way, showing the whole sky

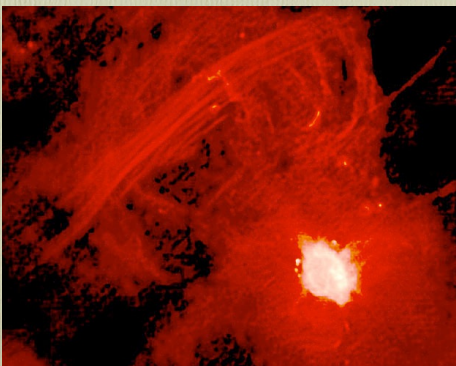
Peter Watson

- If we look at it with radio waves, see very intense source at centre



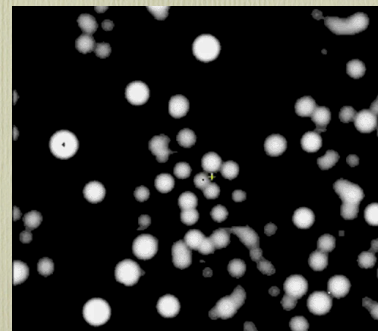
Peter Watson

- which gets brighter as we zoom in



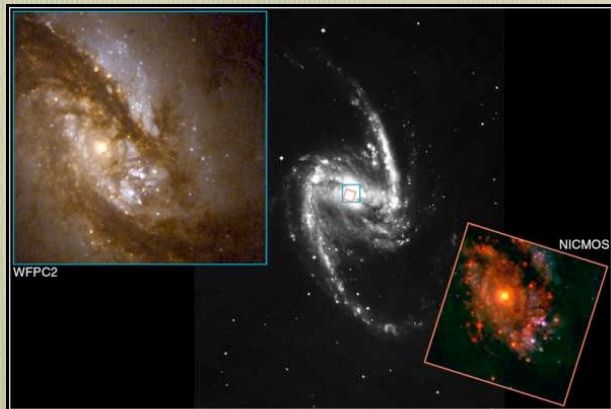
Peter Watson

- The stars there are swirling round something 6 million times as heavy as the sun



Peter Watson

- All galaxies seem to have a huge black hole at the centre



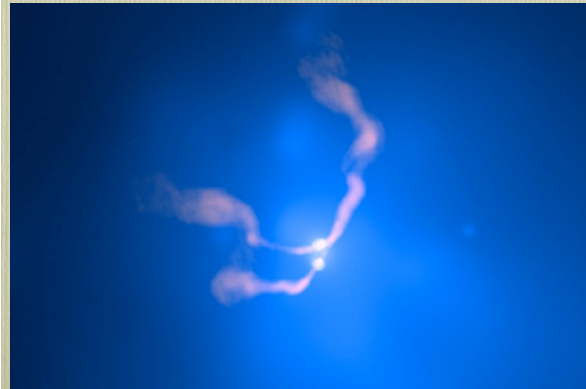
Barred Spiral Galaxy NGC 1365

NASA and M. Carollo (Columbia University) • STScI-PRC99-34a

HST • WFPC2 • NICMOS

Peter Watson

- And this is maybe where it is happening now:
- Two galaxies have collided and the black holes seem to be coalescing



3C75 X-rays
from Chandra

Peter Watson

Spiral Galaxies

- Some are spread out, like NGC6946
- About 10 billion stars
- About 20,000 parsecs across
- Can't see individual stars: red patches are "star nurseries"



Peter Watson

- Some are tightly wound up, like M31 (the Andromeda galaxy)



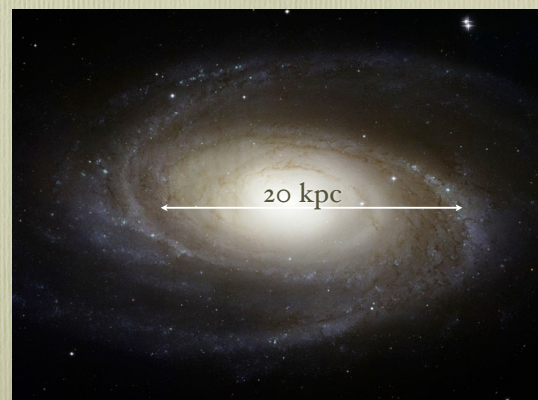
Peter Watson

- Some galaxies have grabbed hold of other galaxies
- This is M51



Peter Watson

- The **smallest** things we will talk about are galaxies: typically 10 billion stars



M81 in Ursa Major
HST picture

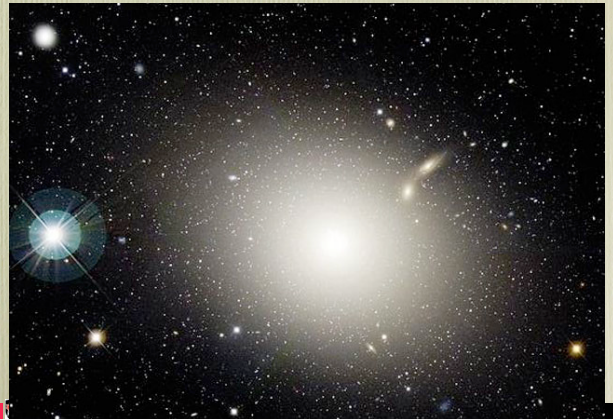
Peter Watson

- Some are seen side on
- NGC4565
- Note the dust clouds



Peter Watson

Elliptical Galaxies: M87 looks dull, but it's huge: one trillion stars like the sun

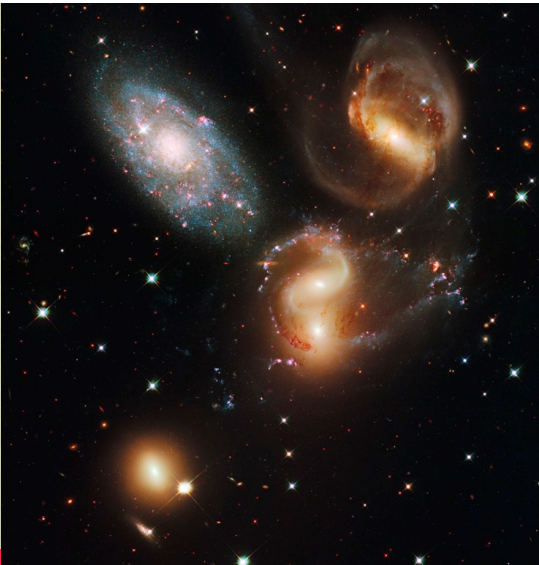


- The Coma cluster is made up of 10000 galaxies
- Apart from one bright star, almost all the objects are galaxies



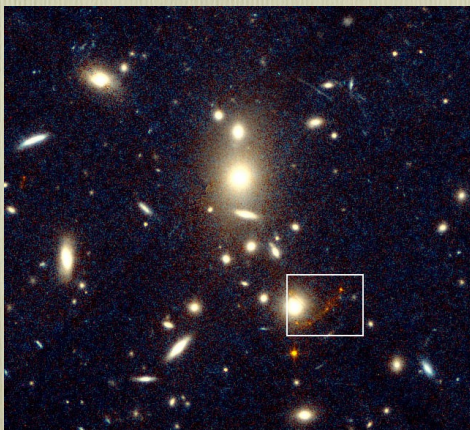
Peter Watson

- Galaxies group together
- Some are tightly packed
- Stefan's quintet



Peter Watson

- But there are more



Peter Watson

- And the further out we go, the more we see



So how big is the universe?



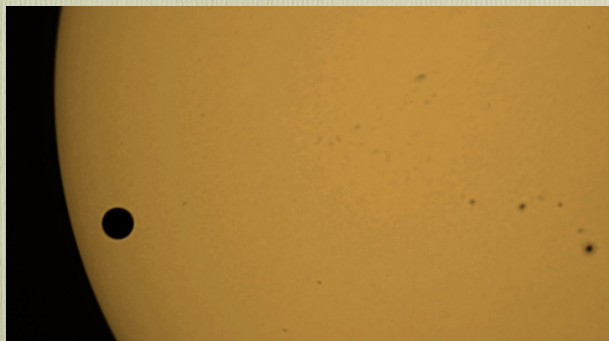
Peter Watson

So WHY did Captain Cook go to Tahiti?



Peter Watson

Venus crosses the sun twice every 100 years



Picture by Etienne Rollin



Peter Watson

The People of Tahiti built this memorial to Captain JAMES COOK RN, who observed the Transit of Venus near this site on 3 June 1769 during his first Pacific voyage, and gave the name Point Venus.

He returned here on his following two voyages.

Erected 1901, proposed by the Royal Society and the Royal Geographical Society.

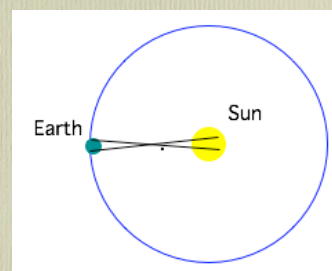
Restored 2011 by the Government of French Polynesia at the suggestion of the Captain Cook Society.



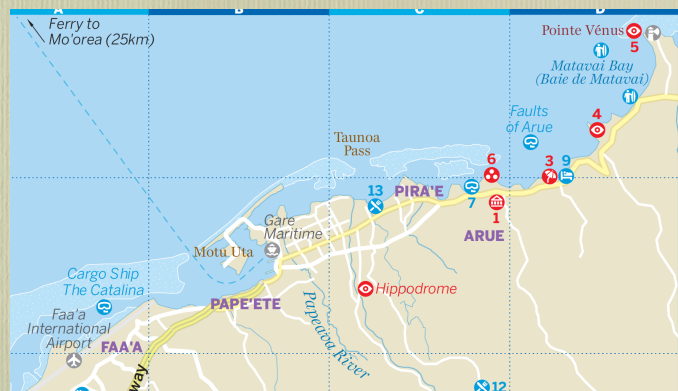
Peter Watson

So WHY did Captain Cook go to Tahiti?

- How big is the universe?
- One astronomical unit (AU) is the distance from the earth to the sun
- 150 million km or 8 light minutes

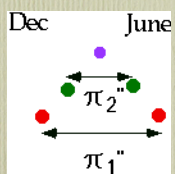
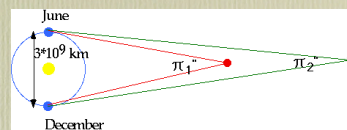


Peter Watson



Peter Watson

- Can use "parallax"

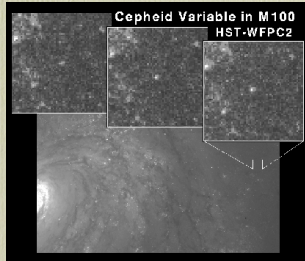


- Position of star will vary over year
- Takes us out to 100 parsecs (400 light years)



Peter Watson

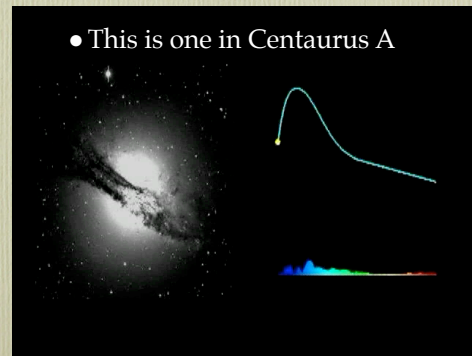
- Cepheids are supergiant stars which pulsate regularly
- Take us out to 20 million parsecs (20 Mpc which is 100 million lightyears)



NASA, HST, W. Freedman (CIW), R. Kennicutt (U. Arizona), J. Mould (ANU)

Peter Watson

- Type Ia Supernova
- Very bright, Very rare (1 / galaxy / century)
- And they are all the same



Peter Watson

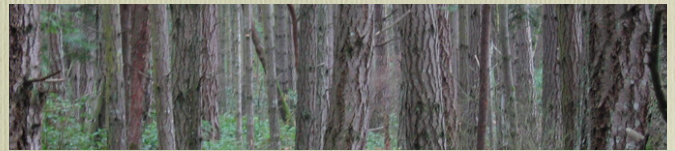
- So how big is the universe?
- Could it be infinite?

• **NO**

Olber's paradox: why is the sky dark at night?

Peter Watson

If you are in the centre of a forest, what do you see?



- Trees in every direction

Peter Watson

If you are in a forest and you don't see trees in all directions, what is going on?

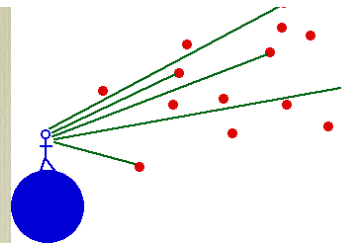
- You are close to the edge

Peter Watson

- If universe is

1. infinite
2. uniformly filled with stars

- Any line of sight will end on a star, as bright as the sun.
- so night sky will be bright



Except that
it isn't

Peter Watson

Apparent Ways out

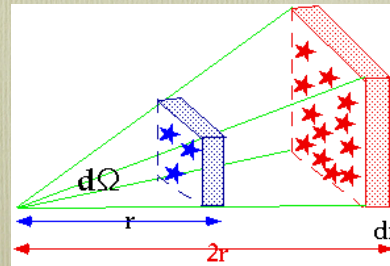
- Obviously universe is not uniform for stars
- But it is for galaxies



Peter Watson

Apparent Ways out

- Light from stars falls off with distance: twice as far means 1/4 the light
- But the number of stars increases as we move out, so the effects cancel.



Peter Watson

Apparent Ways out

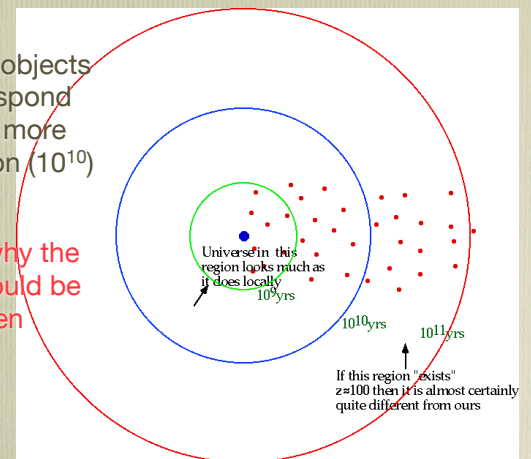
- “Stuff” (interstellar matter) dims distant stars
- But the matter would by now be hot and radiating



Peter Watson

Correct Way Out

- Very distant objects would correspond to an age of more than 10 billion (10^{10}) years
- No reason why the universe should be the same then



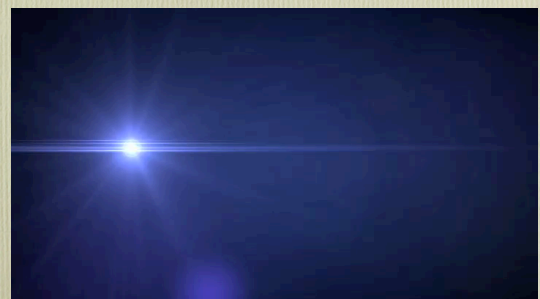
Peter Watson

- So we (almost) must have a universe with a beginning: cannot be infinite in both space and time.
- And finally: the crucial discovery



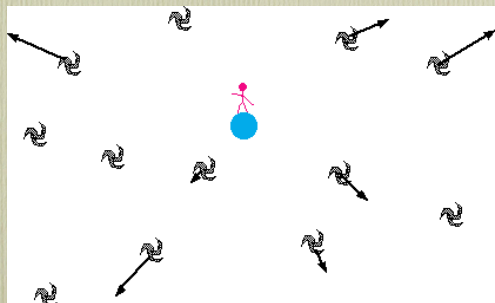
Peter Watson

- Blue shift: something moving towards us (and appears hotter)
- Red shift: something moving away from us (and appears cooler)
- Note no information about transverse motion



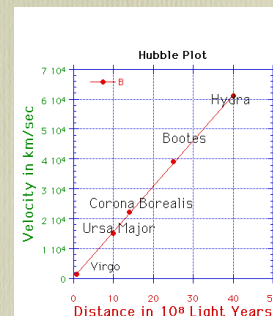
Peter Watson

- Found in 1920's (Hubble, Humason, Slipher) that faint galaxies are receding from us:
- fainter the galaxy, faster the recession.



Peter Watson

- Hubble was able to measure distances to closer clusters
- More distant galaxies move faster
- a galaxy at 1 Mpc is receding from us at 70 km/s



Peter Watson

• i.e the universe is expanding

• So can we say when and where the universe began?

Come back for the sequel!

Peter Watson

- Sources: most pics from
- APOD (Astronomy Picture of the Day)
- NASA
- European Space Observatory
- Notes will be posted at www.physics.carleton.ca/~watson/

Peter Watson