

# The Size of the Universe

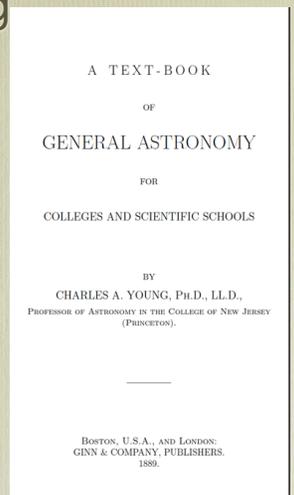


*We come spinning out of nothingness, scattering stars like dust.* Rumi



Peter Watson, Dept. of Physics

# A little Time-Travelling



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 assume .....that 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.



Peter Watson

- Kelvin-Helmholtz time: How long would the sun run on gravity?
- Running at present power output lifetime ~ 24 million years
- (Remember we haven't discovered the nucleus yet and don't have  $E = mc^2$ )



Peter Watson

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

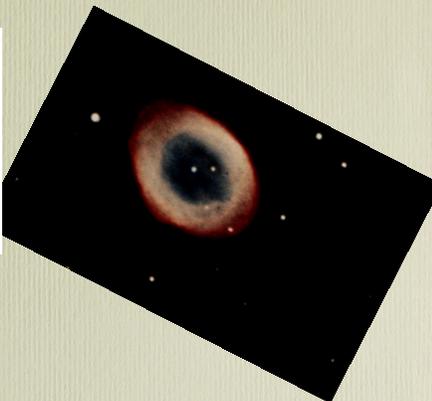
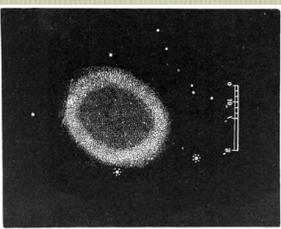
**Central Suns.** A number of speculative astronomers, **Mödl** perhaps most prominently, have held the belief that there is a central sun standing in some such relation to the stellar system as our sun does to the solar system. It is hardly necessary to say that the notion has not the slightest foundation, or even probability. **Lambert** supposed many such suns as the centres of subordinate stellar systems, and because we cannot see them, he imagined them to be dark.

... of course, our system so limited has at any moment a perfectly definite centre of gravity. There is no reason why some particular star may not be very near that centre, and in that sense a central sun" is possible; but its central position would not give it any pre-eminence ..... or put it in any such relation to the rest of the stars as the sun bears to the planets

**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 nebulosity 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 nebulosity is really at the star.

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



**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!

**Structure of the Heavens.** Our space does not permit a discussion of the untenable conclusions reached by Herschel and others by combining the unquestionable data derived from observation, with the unfounded and untrue assumptions that the stars are substantially of a size and spaced at approximately equal distances. ....we can safely draw ... a few general conclusions

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. I... 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.



## Physics as a Creation Myth. Part 1

- A Creation Myth?????????????



Enuma Elish tablets : the first (written) Creation Myth

From The First Tablet

When in the height heaven was not named,  
And the earth beneath did not yet bear a name,  
And the primeval Apsu, who begat them,  
And chaos, Tiamut, the mother of them both  
Their waters were mingled together,  
And no field was formed, no marsh was to be seen;  
When of the gods none had been called into being,  
And none bore a name, and no destinies were ordained;  
Then were created the gods in the midst of heaven,

Lahmu and Lahamu were called into being...  
Ages increased,...  
Then Ansar and Kisar were created, and over them....  
Long were the days, then there came forth....  
Anu, their son,...  
Ansar and Anu...  
And the god Anu...  
Nudimmud, whom his fathers, his begetters....  
Abounding in all wisdom,...  
He was exceeding strong...  
He had no rival --



- A Creation Myth?????????????

- In the beginning the Universe was created. This has made a lot of people very angry and has been widely regarded as a bad move. Many people believe that it was created by some sort of God, though the Jatravartid people of Viltvodle Six firmly believe that the entire Universe was in fact sneezed out of the nose of a being they call the Great Green Arkleseizure.



The Jatravartids, who live in perpetual fear of a time that they call "The Coming of the Great White Handkerchief", are small blue creatures . However, the Great Green Arkleseizure theory was not widely accepted outside Viltvodle Six, and so one day a race of hyper-intelligent beings built themselves a gigantic computer called Deep Thought to calculate once and for all the answer to the Ultimate Question of Life, the Universe and Everything.

which was, of course,



# 42

From "The Hitchhiker's Guide to the Galaxy", Douglas Adams

- Ingredients for a creation myth:
  1. Doesn't it make you feel humble!
  2. So how did it all begin?
  3. What's going to happen in the end?
  4. There is still a big dark mystery out there.
  5. Things were so much simpler back then
  6. Fortunately, there is a special place for us.
  7. But what happened before?
  8. What a beautiful story!



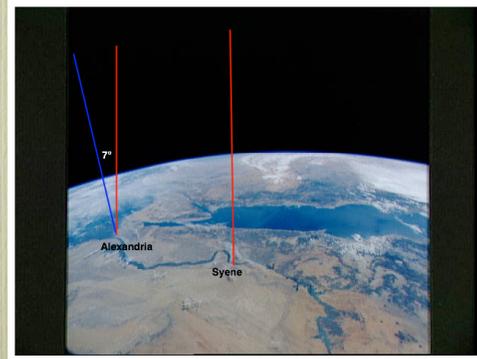
## Doesn't it make you feel humble!

- Space is big. Really big. You won't believe how vastly, hugely, mind-bogglingly big it is. Hitchhiker's guide to the Galaxy.
- How big is the universe?
- Could it be infinite?



## Eratosthenes: 276-195 BC

- How big is the earth?



- Sun is vertically above Syene (Aswan) whereas it is  $7^\circ$  off the vertical at Alexandria,
- Distance is 720 km
- Gives  $\sim 5900$  km instead of 6400.
- First step into finding how big the universe is!
- How far is the Moon?

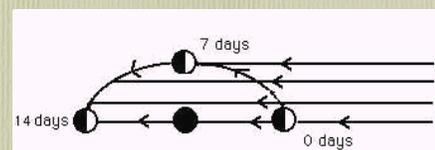


- Moon is about  $1/2^\circ$  in the sky
- Can use the moon as a "Screen" on which the shadow of the earth is projected:
- The shadow of the Earth  $\sim 2^\circ$  wide.

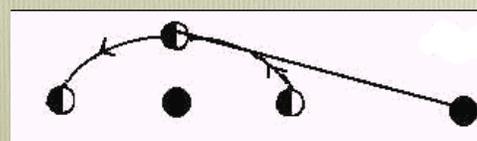
Photo by Anthony Ayiomitis



- Much harder: If the sun was infinitely far away, then half-moon would occur exactly half way through month.



- If the sun is closer, half-moon will occur earlier



- Very hard to estimate when half moon occurs

- Get earth-sun distance ~20 times Earth-Moon distance ~7,500,000 km. (actually ~150,000,000 km)

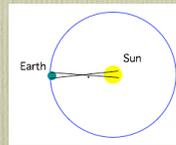
- Implies the sun is a red-hot stone bigger than Greece! (Anaxagoras)



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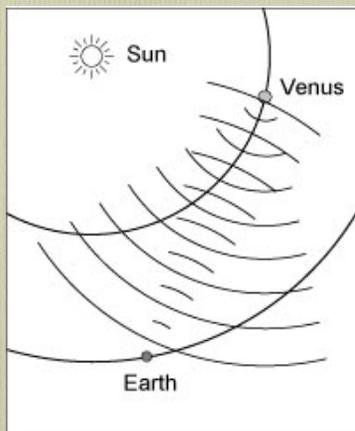
- One astronomical unit (AU) is the distance from the earth to the sun

- 150 million km or 8 light minutes



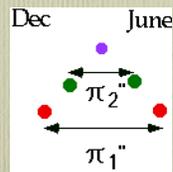
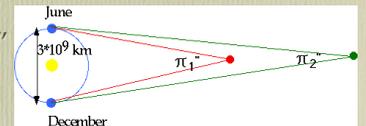
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## Now radar-ranging



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- Stars: use "parallax"



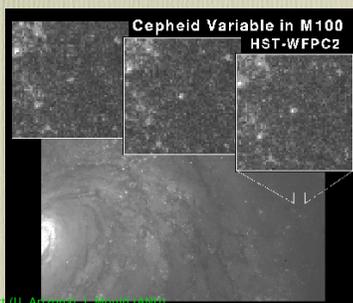
- Position of star will vary over year

- 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)



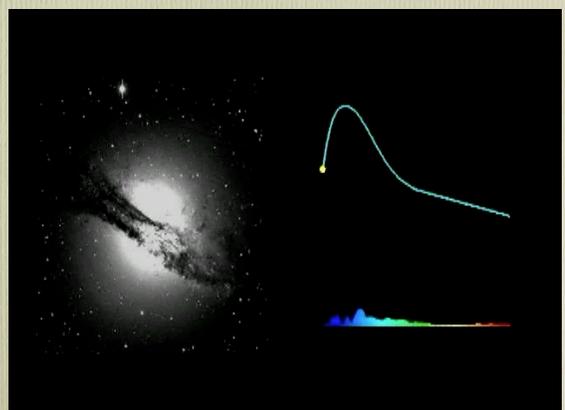
NASA, HST, W. Freedman (CIW), R. Kennicutt (U. Arizona), J. Martin (AT&T)



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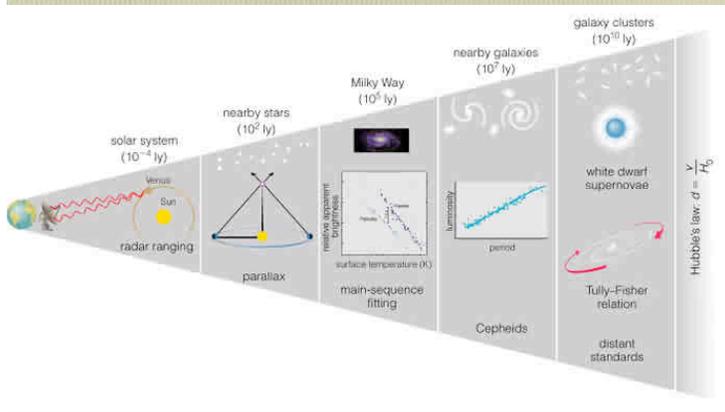
- Type 1a Supernova: very rare (1 / galaxy / century), very bright and they are all the same

- This is one in Centaurus A



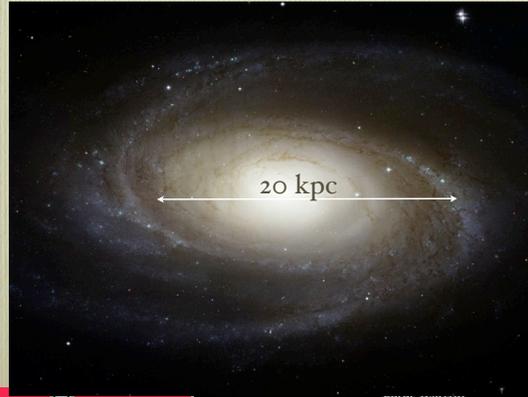
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- We have a lot of methods for finding distances:



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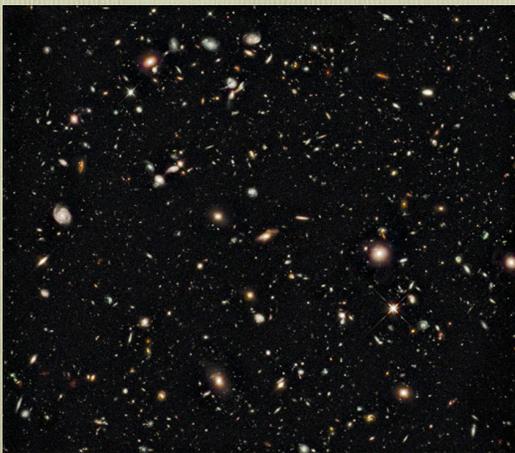
- The smallest things we will talk about are galaxies:
- typically 10 billion ( $10^{10}$ ) stars and a size of 20000 pc ( $10^{20}$  m)



- M81 in Ursa Major: HST picture

Peter Watson

- The further out we go, the more we see



Peter Watson

- But most of the time we'll be talking about clusters of galaxies: this is Virgo.

- Typically 1 million billion ( $10^{15}$ )  $M_{\odot}$  and a size of 2 million parsecs (2 Mpc or  $10^{22}$  m)



Peter Watson

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

• **NO**

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



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



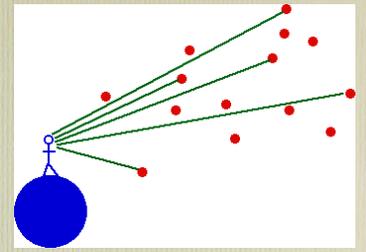
- Trees in every direction

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

- If universe is
  - infinite
  - uniformly filled with stars



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

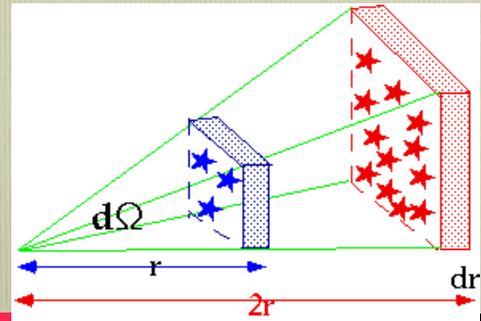
Except that it isn't

# Apparent Ways out

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

# 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.

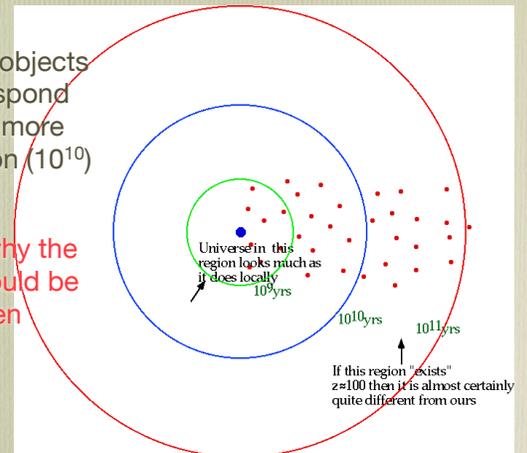


# Apparent Ways out

- Absorption by interstellar matter dims distant stars
- But the matter would by now be hot and radiating

# 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



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



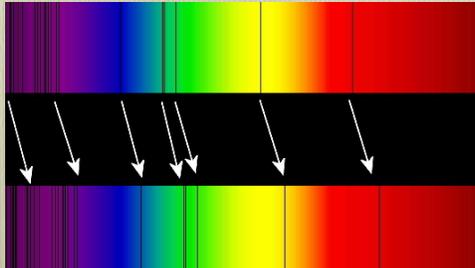
## Doppler shift

- Universal for all waves, including sound
- Wave gets “stretched out” by motion
- Can measure how fast something is moving by looking at the light

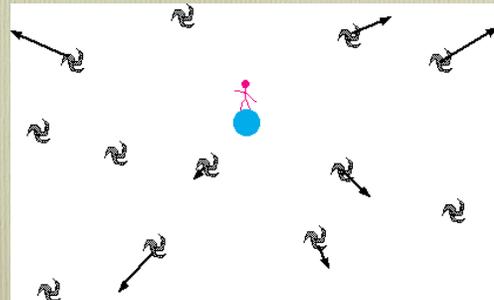


## Note: can't use just the colour of stars

- How would we know if it's just a blue star or a star moving towards us?
- Can use these spectral lines since they **all** get shifted by the same amount



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



Credit & Copyright: Günter Kerschhuber (Galberg Observatory)

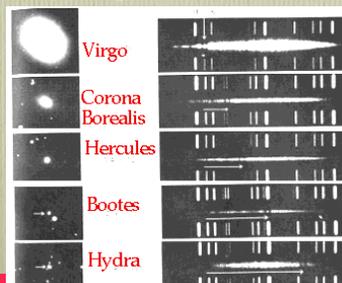
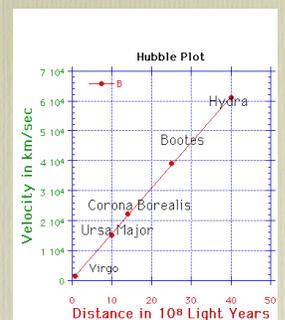
- e.g Virgo cluster



Credit & Copyright: David Malin (AAO, AATB)

- e.g Hydra cluster

- Hubble was able to measure distances to closer clusters
- velocity increases with distance
- a galaxy at 1 Mpc is receding from us at 70 km/s



- i.e the universe is expanding
- Can use recession velocity as a surrogate for distance

•  $v = Hd$



- 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

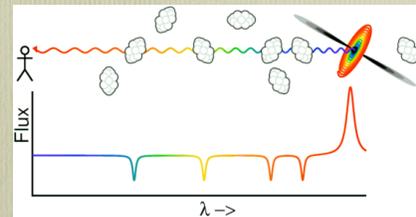


- This one is imaged 4 times (the Einstein cross)
- Can just see the galaxy.



## Between the galaxies?

- The most luminous distant objects are the quasars
- When we look at spectrum of intervening gas we can see hydrogen gas
- As the gas between us and the quasar has various red shifts, we can map out the hydrogen



Note that this gives us the best proof that the laws of physics don't change

- i.e. an atom of hydrogen gas that is five billion years old and a gigaparsec away has the same physics as an atom on earth!



## An unexpected spin-off: Hanny's Voorwerp

Amateurs have been encouraged to look at the SDSS images to classify galaxies. This was found by Hanny von Arkel  
What is it?



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

Come back for the sequel!

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

