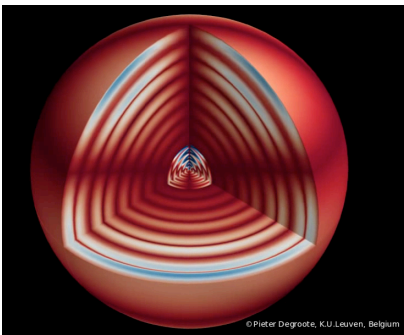




Where are we going?

1. The Big Bang 1: Physics as a Creation Myth
2. The Big Bang 2: the Nightmare Continues
3. Can We Time-Travel? 10 Answers!

Mostly cannot see inside stars

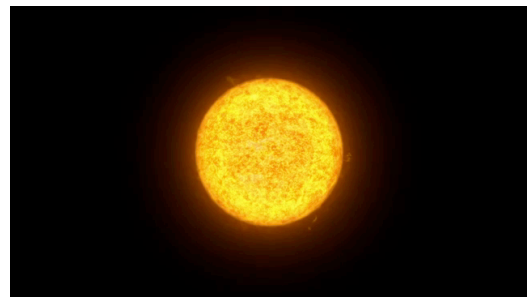


Sun is only one close enough to see neutrinos

However helio-seismology lets you see inside (like seismology on earth)

Stars vibrate like a (3-D) drumhead

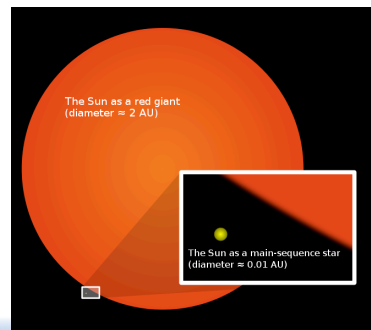
Cepheids change colour, size, brightness



- work by blocking mechanism
- very important since period is proportional to *real* brightness:
- i.e. measure the *apparent* brightness, the period tells you the *actual* brightness, so you know how far away it is



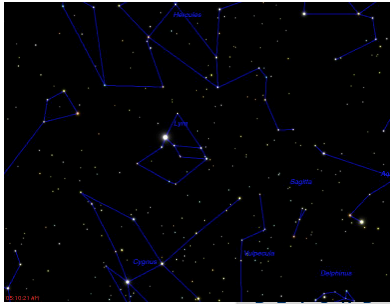
Adulthood is dull



Don't we know it!
Finally star will run low on fuel and expand
Becomes red giant

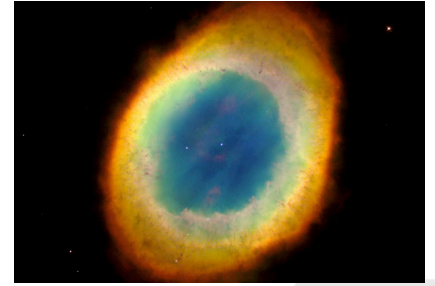
Then

If stars are small, (like the sun) they puff away their outer layers
This is M57 (Ring Nebula)



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- Planetary nebula
- Central star is a white dwarf (50000°C)
- Hot blue gas at centre
- Coolest red gas along the outer boundary.



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- This will happen to the sun, in 5.5 billion years.
- The star blows away its outer layers, so almost all the older ones we knew look like this.



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But we find all sorts of weird shapes.
This is the Cats-eye nebula: looks like successive explosions

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- Mz3: The Ant Nebula.
- Probably magnetic field is creating a "focussed" planetary nebula



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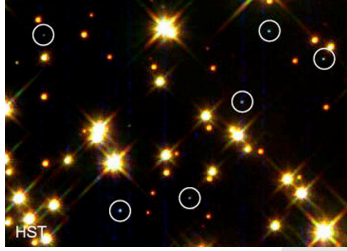
White dwarfs

- After the outer shell has disappeared, we are left with a star about the same mass as sun but size of earth (~10000 km)
- Density: ~1 million: ~ 100,000 times as dense as lead.

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White dwarfs

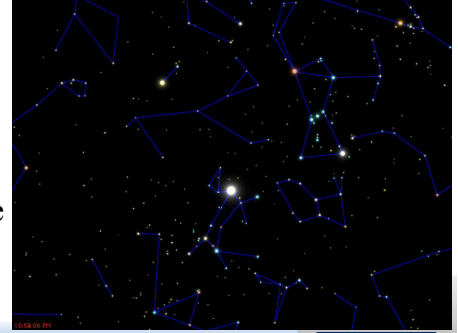
This shows some in M4 (a dense cluster of stars). Since they are small, they cool very slowly.



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Sirius

Brightest star in the sky
Has an almost invisible companion white dwarf

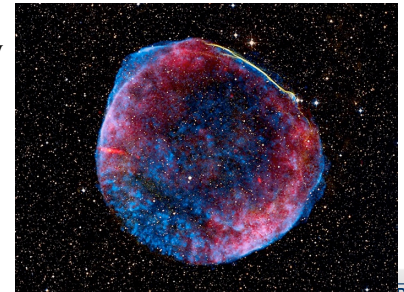


The Eight Burst Nebula
White dwarf and companion, will probably look like Sirius in 100000 years

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If Stars are large....

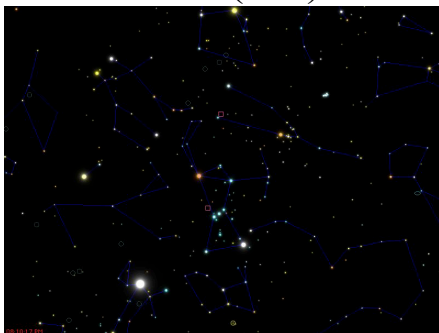
- we get supernovae
- 6 visible in Milky Way over last 1000 years
- SN 1006: Brightest Supernova.
- Can see remnants of the expanding shockwave



Frank Winkler (Middlebury College) et al., AURA, NOAO, NSF

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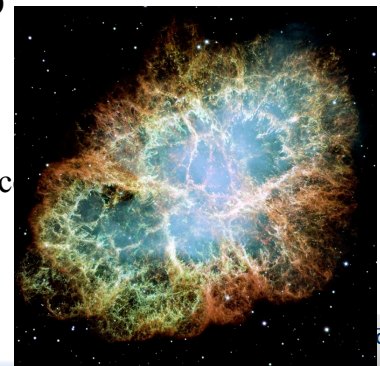
The Crab (M1)



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1054: Crab

- X-rays (in blue)
- + Optical
- Tangled appearance due to trapped magnetic field



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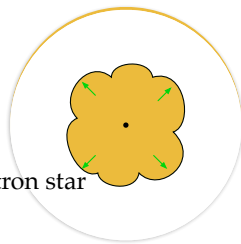
- Recorded by Chinese astronomers as “guest star”
- May have been recorded by Chaco Indians in New Mexico



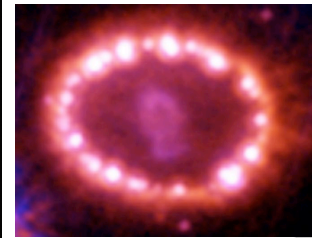
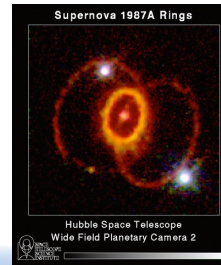
- How do they work?
- Core of star runs out of fuel
- Star collapses, superheats interior
- Shock wave blows off outer layer of star at 1/10 speed of light

What happens to a star after it runs out of fuel?

- Collapses and heats up
- Outer part explodes out,
- Core gets compressed to neutron star or black hole



- Most recent close one was SN1987a
- Must have blown up earlier, leaving ring of material, now illuminated by new shock wave



Surprisingly...

- Most (98%) of the energy doesn't come out as light..
- It's neutrinos
- As the matter falls in, the nu's stream out!

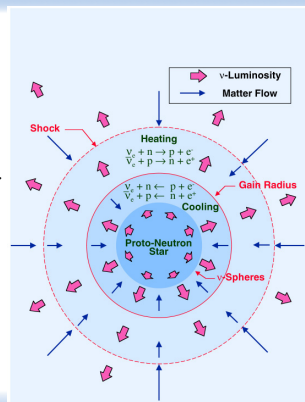
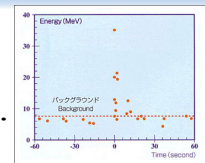
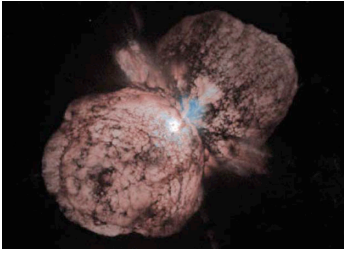


Image credit: TeraScale Supernova Initiative

Which we can see here..



- We would like to catch supernovae before they explode: Possibly



Eta Carinae blew off a lot of material 150 years ago: probably pre-collapse now

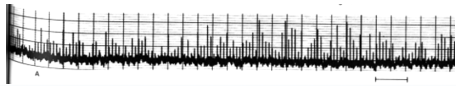
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- NGC 3603: can see formation of stars
- contains Sher 25 surrounded by rings: probably pre-collapse



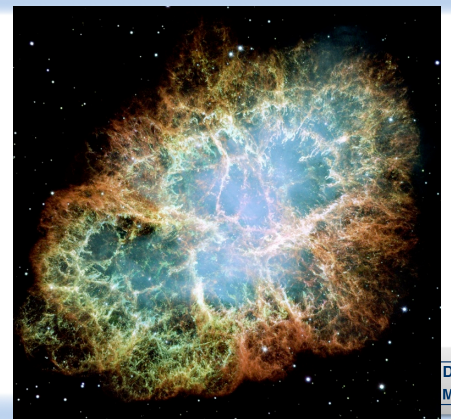
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- Pulsars
- accidentally observed (1968) by Jocelyn Bell etc.
- Very regular radio pulses
- period of 2 ms up to 4 s
- Height of pulse is very irregular



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Best known is Crab.
Supernova remnant
Pulsar at centre
has period of
 $\sim 1/30$ s



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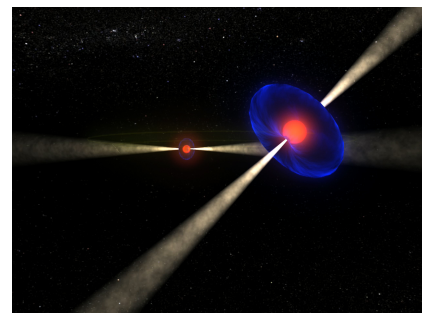
And you can even listen to them

- This is Vela
- And this is PSR 0329+54

Period of Crab measured to be 0.03308471603 s
(i.e. stable to 1 part in billion)

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- Double Pulsar



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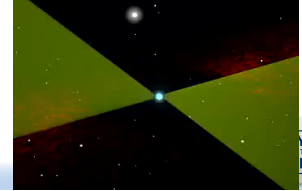
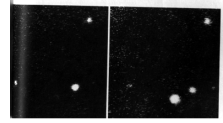
What pulses?

- Now known to be neutron star: predicted by Oppenheimer (yes, that one) in 1935.
- Density ~ atomic nucleus: dime would weigh 2000,000,000 tons!

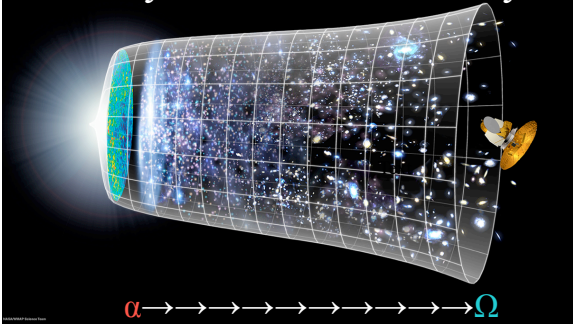


What pulses?

- Charged particles travel along magnetic field,
- can only escape from poles of neutron star.
- Hence "lighthouse" mechanism: we only "see" pulsar when mag. pole points towards us



Physics as a Creation Myth

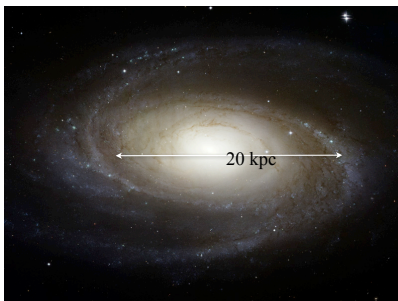


Peter Watson
Carleton
UNIVERSITY



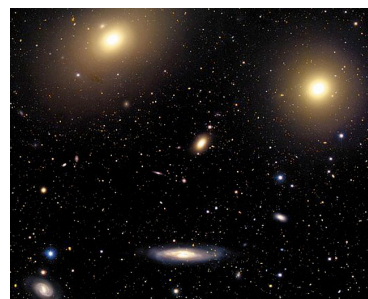
Statutory Warning

- This lecture is for mature audiences only
- Extreme violence may be caused to your preconceptions
- Allergy alert: This talk may contain peanuts
- Allergy alert: This talk may contain ~~peanuts~~ formulas



The smallest things we will talk about are galaxies: typically 10 billion stars and a size of 100000 light years

- M81 in Ursa Major: HST picture



But mostly we'll be talking about clusters of galaxies: Typically 1 million billion M_{\odot} and a size of 10 million light-years (~2 Megaparsecs)



Physics as a Creation Myth.

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



- 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,



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

42

- 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!



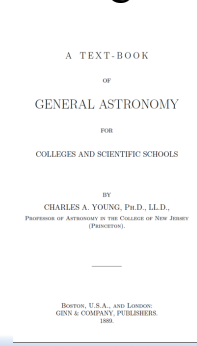
1. Doesn't it make you feel humble!

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

- So how big is the universe?



A little Time-Travelling



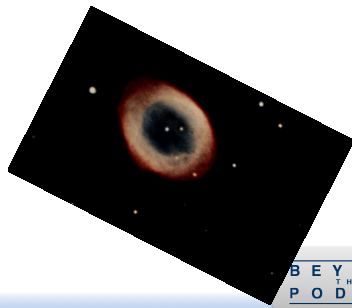
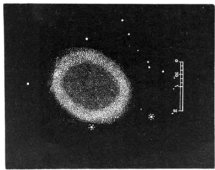
Age of the Solar System. Looking back with imagination we see the sun growing cool through the reversed course of time, becoming ever less and less dense. Some epoch in the past it filled all the space enclosed within the largest orbit of the solar system. How long ago that epoch can say with certainty. If we could assume that all the heat radiated has come from this sun, without subsidy from any original store, we would conclude that the sun's past history must have lasted 15,000,000 or 20,000,000 years.

Well, 500 times older

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.

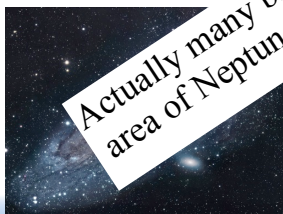
- M57 (Ring Nebula) clearly associated with star, hence at same distance as stars.



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.



Actually many billions times the area of Neptune's orbit!

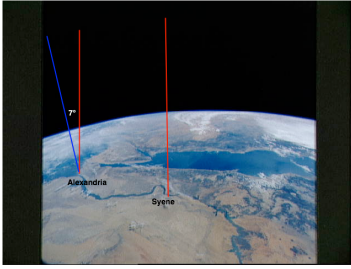


As to the distance of the remotest star in our stellar system, it is impossible to say anything very definite, but it seems quite certain that it must be at least so great that light would require from 10,000 to 20,000 years in traversing it. If one asks what is beyond the stellar system, whether the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

Well, actually one million times bigger

Eratosthenes: 276-195 BC

- How big is the earth?



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- ~5900 km instead of 6400.
- First step into finding how big the universe is!
- How far is the Moon?

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- 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
Ayiomitas

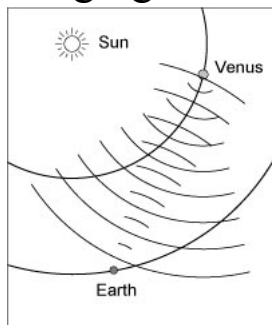
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- $d = 384,400$ km by modern methods.
- How far is the sun?

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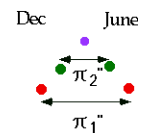
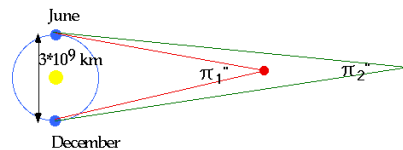
Now radar-ranging

- 150 million km or 8 light minutes



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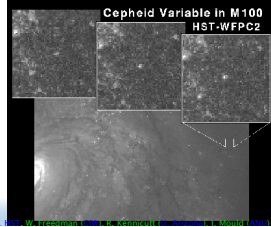
- Stars: use "parallax"



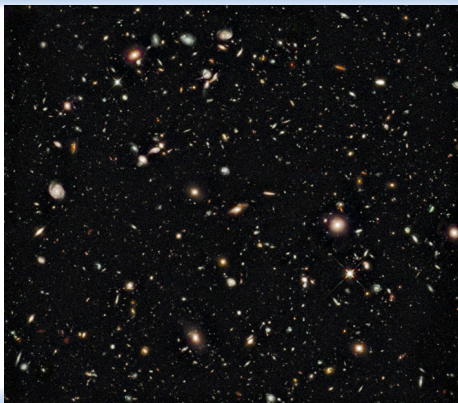
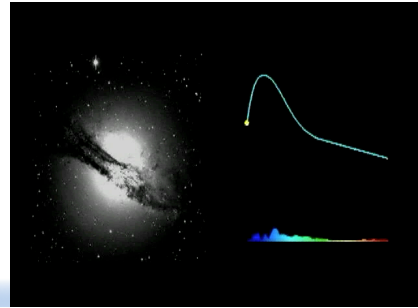
- Position of star will vary over year
- Takes us out to 400 light years

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



- Type Ia Supernova: very rare (1/galaxy/century), very bright and they are all the same
- This is one in Centaurus A



And the further out we go, the more we see

1. 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.

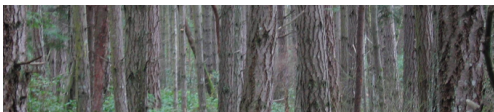
- So how big is the universe?
- Could it be infinite?



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

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

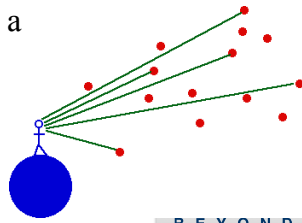
- Trees in every direction



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
 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

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• So we almost **must** have a universe with a beginning

- Cannot be infinite in both space and time.
- And finally: the crucial discovery

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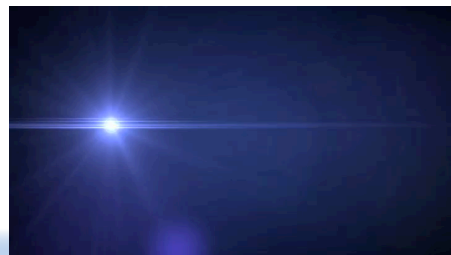
Doppler shift

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



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- Blue shift: something moving towards us
- Red shift: something moving away from us
- Note no information about transverse motion



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- e.g Virgo cluster



Credit & Copyright: Günter Kerschhuber (Galileo Observator)

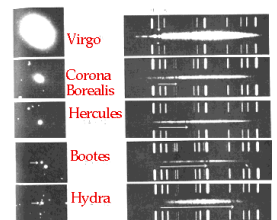
- e.g Hydra cluster



Credit & Copyright: David Malin (AAO, AATB)

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- Hubble found galaxies are receding
- velocity increases with distance
- a galaxy at 1 Mpc (4 million light-years) is receding from us at 70 km/s



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i.e the universe is expanding
Huh?

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