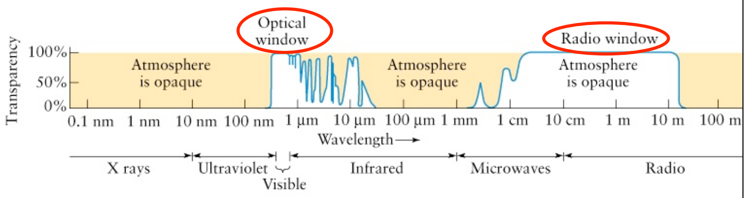
Lecture 6: Multiwavelength astronomy and the Universe

- Astronomy across the electromagnetic spectrum - optical, radio, X-ray
- Redshift and the Hubble law
- The expansion of the Universe and the Big Bang

Atmospheric transparency

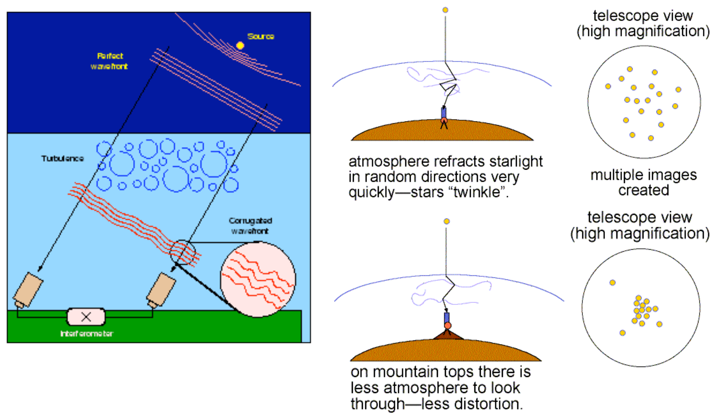


- The Earth's atmosphere absorbs much of the radiation that arrives from space
- The atmosphere is transparent chiefly in two wavelength ranges - the optical and radio 'windows'
- Some wavelengths in the near-infrared also reach the ground, especially at high, dry sites
- For the rest, we have to put instruments into space

Effects of the atmosphere

- Absorption in the atmosphere
  - pair-production, Compton scattering
  - dissociation, ionisation
  - molecular absorption
- Scattering
  - Rayleigh (why we can't see the stars during the day)
- Atmospheric emission
  - thermal fluorescence
- Dispersion, refraction

"Seeing" due to variable refraction



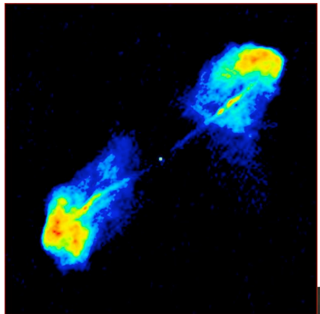
Exploiting the radio window

- Radio telescopes use reflecting dishes to focus radio waves
- Very large dishes provide radio images with moderate resolution
- E.g. for the 76 m diameter Lovell telescope at Jodrell Bank, the Rayleigh criterion for resolution at a wavelength of 20 cm gives

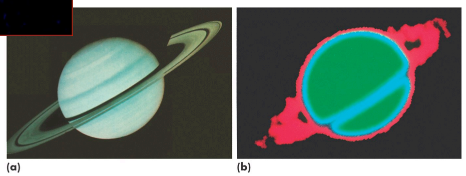
  $\Delta\theta = 1.22\lambda/D = 0.0032$ rad $= 11'$

Higher resolution is achieved with interferometry techniques, which link smaller dishes together.
For example, the Merlin array in the UK spans 217 km, giving it a resolution 217/0.076=2855 times better than the Lovell telescope (i.e. 0.2″ at λ=20 cm).

Radio images



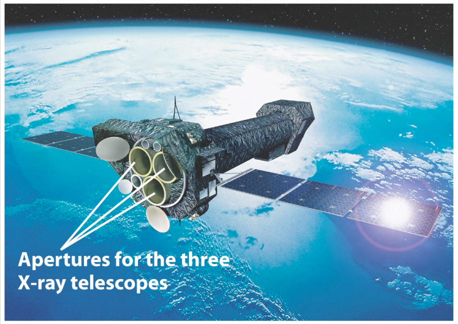
Merlin image of the radiogalaxy 3C438, showing nuclear point-like source and extensive radio jets. Size of image is 23″x23″, and resolution is 0.16″.
(Pat Leahy, Jodrell Bank)



Optical and radio views of Saturn

X-ray astronomy

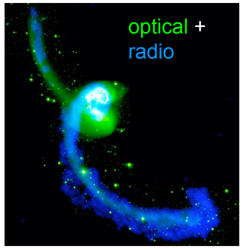
X-rays are emitted by very hot (>10^6 K) gas, and often mark the location of violent cosmic events.

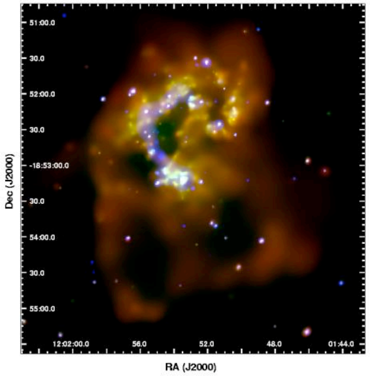


ESA's XMM-Newton orbiting X-ray observatory is the largest X-ray telescope ever flown.

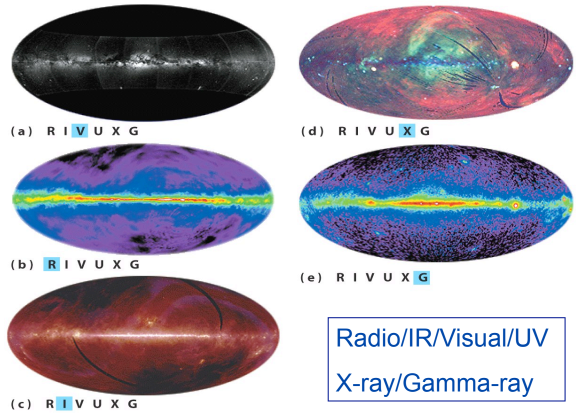
X-ray astronomy

For example - this image shows X-ray emission from a pair of colliding galaxies called “The Antennae”, in which supernova explosions are heating the interstellar gas to ~10^7 K.

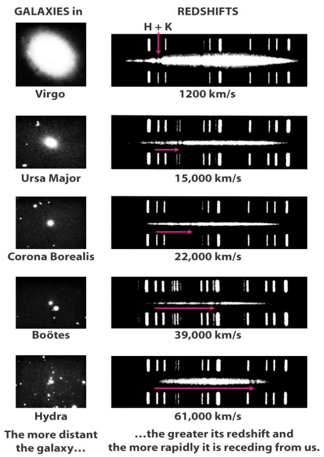




The sky vs wavelength (Galactic coordinates)



The Hubble law relates the redshifts of remote galaxies to their distances from the Earth



Redshift of a receding object

$$z = \frac{\lambda - \lambda_0}{\lambda_0}$$

z = redshift of object

λ_0 = unshifted wavelength of spectral line

λ = shifted wavelength of observed line

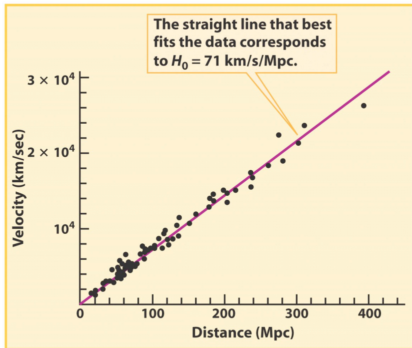
There is found to be a simple linear relationship between the distance from the Earth to a remote galaxy and its redshift.

The Hubble law

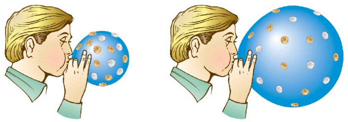
It is common practice to relate redshift to recession velocity, via the formula $z=v/c$. This formula breaks down at high redshifts (e.g. z>0.2).

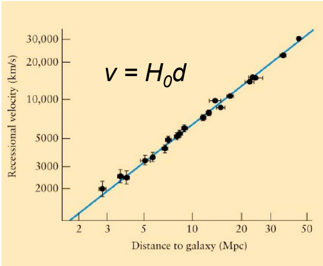
If z is expressed as a recession velocity in this way, then the Hubble law can be written $v=H_0d$.

The value of the Hubble constant, H_0, is close to 71 km s^{-1} Mpc^{-1}



The universe is expanding





- Hubble's law shows that more distant galaxies have higher recessional velocities - i.e. the Universe is <u>expanding</u>.
- It is found to be the same in all directions (isotropic).
- An expanding balloon model is helpful.
- Extrapolating this expansion backwards, at some finite time in the past all the galaxies must have been coincident - the Big Bang.
- If the expansion velocity of the Universe has remained constant, then the Hubble constant immediately gives us the age of the universe $t=1/H_0$=14 Gyr. (1 Gyr=10^9 yr)

The age of the Universe

deceleration parameter $q = -dH/dt$

- A Universe whose expansion decelerates strongly would be younger (e.g. blue or purple lines)
- An accelerating Universe would be older
- In practice, we now believe that our Universe is following an expansion law like the orange line, with initial deceleration followed by acceleration
- We are now in the *accelerating* phase