640-245 Electromagnetism & Special Relativity

Doppler Shift

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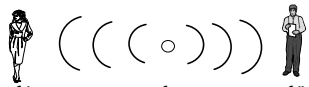
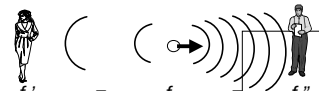
The Doppler Effect

- Have Doppler effect for sound
- Have equivalent effect for light
  - different rules apply because there is no medium for light
- Light-source at rest:



f' = *f* = *f"*

- Light-source in motion:



f' = *f* = *f"*

The Doppler Effect

- When the light-source is approaching, the colour appear bluer than normal - *BLUE SHIFT*

$$f'' = \left(\frac{1+v}{1-v}\right)^{\frac{1}{2}} f$$

- When the light-source is receding, the color appears redder than normal - *RED SHIFT*

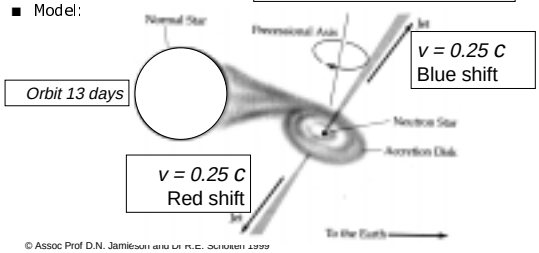
$$f' = \left(\frac{1-v}{1+v}\right)^{\frac{1}{2}} f$$

f' < *f* < *f"*

The Doppler Effect: Case study 1 - SS433

- SS433 - the strangest object in our galaxy
- Located 18,000 light years distant, inside our galaxy
- Optically 14th magnitude star
- Spectrum is very strange
- Model:

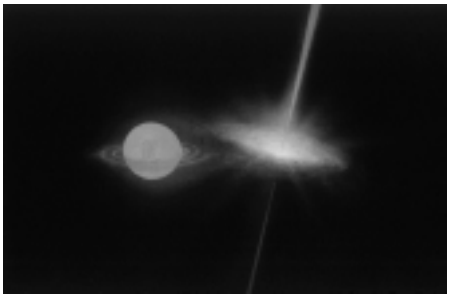
Precession period 164 days



v = 0.25 c
Blue shift

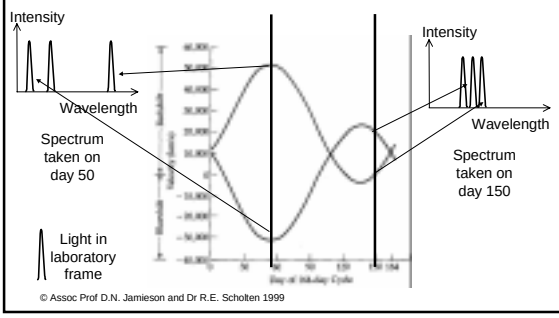
v = 0.25 c
Red shift

The Doppler Effect: Case study 1 - SS433

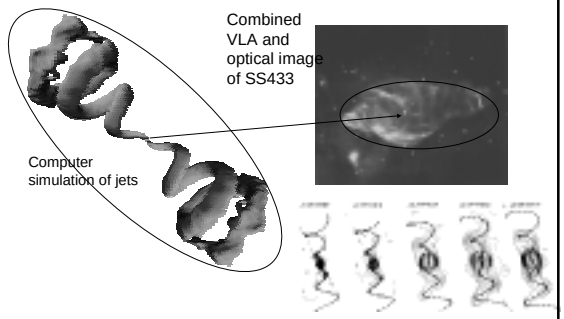


The Doppler Effect: Case study 1 - SS433

- The Doppler effect was the key to understanding the model



The Doppler Effect: Case study 1 - SS433

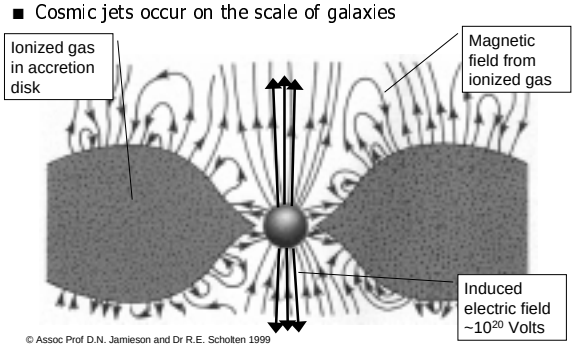


The Doppler Effect: Case study 2 - Cosmic Jets

(movies)

The Doppler Effect: Case study 2 - Cosmic Jets

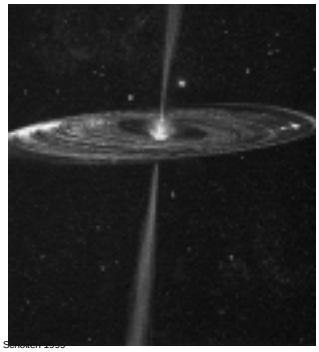
- Cosmic jets occur on the scale of galaxies



Case Study 2: Cosmic Jets

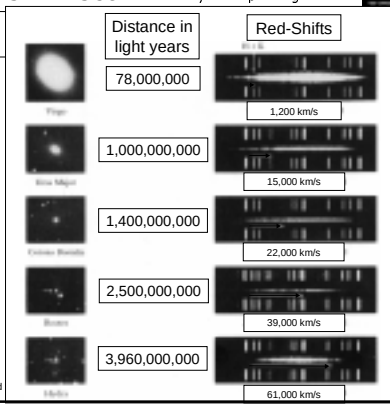
The Doppler Effect: Case study 2 - Cosmic Jets

- Light emission from jets: gamma rays at source fading to radio waves far out
- Light from jets strongly Doppler shifted
- Light from accretion disk also Doppler shifter



The Doppler Effect: Case study 3 - Expanding Universe

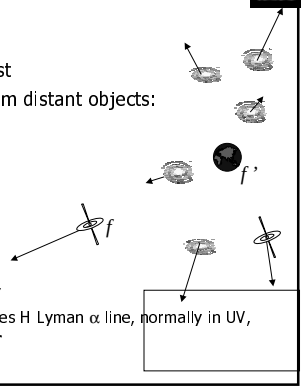
- H + K lines from ionized Ca are visible in many galaxies
- These lines are red shifted
- Velocity from red-shift increases with distance
- Universe is expanding!



The Doppler Effect: Case study 3 - Expanding Universe

- Universe is expanding
- Distant objects recede fastest
- Define *red-shift z* of light from distant objects:

$$z = \frac{f - f'}{f'} = \frac{\lambda - \lambda'}{\lambda}$$



- Examples
  - Most distant quasar $z = 4.897$
  - 4C41.7 (galaxy) $z = 3.8$ Implies H Lyman α line, normally in UV, shifted into yellow! $v = 0.92c$

Special Relativity: Summary

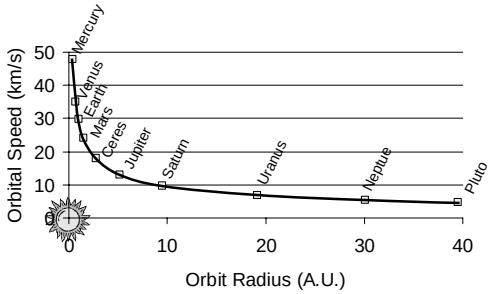
- Laws of Physics are the same for everybody
  - Therefore cannot measure an absolute velocity
- Speed of light is the same for everybody
  - Time dilation
  - Lorentz contraction
  - Mass increase
- Speed of light is the maximum possible speed
  - Duration of intensity fluctuations provide upper limit on physical size
- Relativistic Doppler shift
  - Red-shift for receding objects
  - Blue shift for approaching objects

Missing Mass: Dark Matter

- Only about 10% of the mass of our galaxy is visible!
- How do we know this?
- Answer: Stars orbit inside galaxies not like the planets in our solar system!
- They orbit as if they were embedded in a vast solid sphere!
- Why?
- Answer: Dark matter!

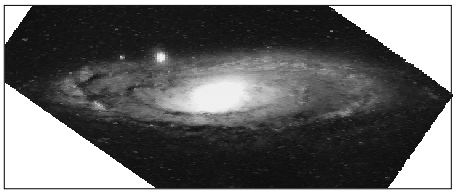
Missing Mass: Orbit of planets

- Planets close to the Sun must orbit fast



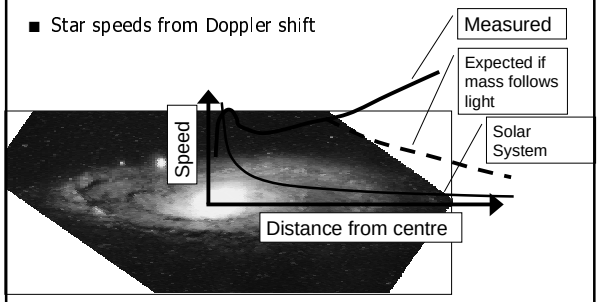
Missing Mass: Orbits of stars in galaxies

- In a galaxy, most of stars are in the central bulge
- Therefore expect rotation curve to be similar to that of the solar system, particularly for stars in spiral arms
- Don't see that!



Missing Mass: Orbits of stars in galaxies

- Star speeds from Doppler shift



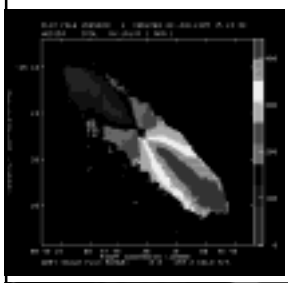
Evidence for Dark Matter: STARBURST GALAXY - NGC 253

NGC 253 is a spiral galaxy in the southern hemisphere constellation of Sculptor.

It is a starburst galaxy, meaning that an unusually large amount of star formation activity is taking place.

Optical image of NGC 253 from the Anglo-Australian Telescope (Siding Springs, Warrambungle National Park).

Radio Images of NGC 253



This image shows a map of the velocity field of NGC 253.

This uses false colour to represent the speeds at which different parts of the galaxy are moving relative to us on Earth.

The relative scale shown on the right is in kilometres per second. The red areas are moving away from us, while the blue/black areas are moving towards us.

Missing Mass: Orbits of Stars in Galaxies

- Expect outer stars to orbit slowly (like outer planets in our Solar System)
- Don't see this: All stars seem to orbit at similar speeds
- Behave as if the galaxy is embedded in a huge spherical lump of matter that is invisible: Dark matter