15.4 Quasars and Other Active Galactic Nuclei

• Our Goals for Learning

  • What are quasars?
  
  • What is the power source for quasars and other active galactic nuclei?
  
  • Do supermassive black holes really exist?
What are quasars?
If the center of a galaxy – the galaxy’s nucleus – is unusually bright we say that the galaxy hosts an active galactic nucleus or AGN.

Quasars are the most luminous examples of AGN.

Active Nucleus and optical jet in M87
The highly redshifted spectra of quasars indicate large distances.

From brightness and distance we find that luminosities of some quasars are more than a trillion times the Sun’s.

Variability shows that all this energy comes from region smaller than the solar system.
From the fact that quasars usually have very large redshifts, we can conclude:

1. They are generally very distant.
2. They were more common earlier in the universe.
3. Galaxy collisions might switch them on.
4. Nearby galaxies might harbor quasar remnants.
Galaxies around quasars sometimes appear disturbed by collisions.

Quasars fueled by gas concentrated in nucleus by galaxy collisions.
Radio galaxies contain active nuclei generating vast, straight jets of plasma. The plasma (ionized gas) emits radio waves that we can detect.
Jets of radio galaxies moving through gas in galaxy clusters can be deflected.
What is the power source for quasars and other active galactic nuclei?
Accretion of gas onto a supermassive black hole appears to be the only way to explain all the properties of quasars.
Energy from a Black Hole

- Matter falling towards a black hole gains speed (turns gravitational potential energy into kinetic energy)
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- Friction in an accretion disk turns kinetic energy into thermal energy (heat & light)
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- Friction in an accretion disk turns kinetic energy into thermal energy (heat & light)
- Hot disk emits optical and ultraviolet light
- Matter spiralling into a black hole can radiate energy equal to 10-40% of the matter's mass-energy $E = mc^2$ ... much more efficient than fusion (1% of $mc^2$)
An active galactic nucleus (left-hand spot) can eject a blob of plasma (right-hand spot) moving at nearly the speed of light.

Speed of ejection suggests that a black hole is present.
Jets are thought to come from twisting of magnetic field in the inner part of accretion disk.
Jets may be produced only when black hole is rapidly spinning (not all black holes spin rapidly, so not all quasars have jets).
Radio galaxies don’t appear as quasars because dusty gas clouds block our view of accretion disk.

(but some radio quasars do exist)
Quasar feedback

• Jets and other feedback from quasars affect the host galaxy
• Gas is heated, ionized, pushed away from nucleus, eventually stopping quasar from shining and galaxy from forming stars
• To do all that in a more massive galaxy requires a more massive black hole
Galaxies with large bulges have large black holes.

...while those with smaller bulges have smaller black holes.
Quasar feedback

• Jets and other feedback from quasars affect the host galaxy
• Gas is heated, ionized, pushed away from nucleus, eventually stopping quasar from shining and galaxy from forming stars
• To do all that in a more massive galaxy requires a more massive black hole
• Quasar can even affect the surrounding galaxy cluster, if the host galaxy is in a cluster … see black hole animations
Do supermassive black holes really exist?
Orbits of stars at center of Milky Way stars indicate a black hole with mass of 4 million $M_{\text{Sun}}$. 

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Orbital speeds and distances of gas orbiting in the center of M87 indicate a black hole with mass of 3 billion $M_{\text{Sun}}$. 
Black Holes in Galaxies

• Many nearby galaxies – perhaps all large ones – have supermassive black holes at their centers
• These black holes seem to be dormant active galactic nuclei
• All large galaxies probably passed through a active galactic nucleus stage earlier in time
What have we learned?

• **What are quasars?**

  Some galaxies have unusually bright centers which are called **active galactic nuclei**.

• A **quasar** is a particularly bright active galactic nucleus. Quasars are generally found at very great distances, telling us that they were much more common early in the history of the universe, when galaxy collisions were more common.
What have we learned?

- **What is the power source for quasars and other active galactic nuclei?**
- Supermassive black holes are thought to be the power sources for active galactic nuclei. As matter falls into a supermassive black hole through an accretion disk, its gravitational potential energy is transformed into thermal energy and then into light with enormous efficiency.
What have we learned?

• Do supermassive black holes really exist?

• Observations of orbiting stars and gas clouds in the nuclei of galaxies suggest that all large galaxies may harbor supermassive black holes at their centers.
Activity 39, pages 139-140: Superluminal (faster-than-light) motion in quasar jets?

- A quasar ejects a blob of gas on day zero.
- Blob travels at \(\frac{13}{14}\) times the speed of light
- Light from blob on day zero heads towards Earth, but blob travels in a slightly different direction.
Apparent superluminal (faster-than-light) motion in quasar jets!

- A quasar ejects a blob of gas on blob day zero.
- Blob travels at 13/14ths of the speed of light “c”
- Light from blob on day zero heads towards Earth, but blob travels in a slightly different direction.
- Blob moving slower than light almost in Earth’s direction almost catches up with the light it emitted earlier, so blob appears to move faster than light.