Active Galaxies

3C 273

Jet

10 arcsec
Guiding Questions

1. Why are quasars unusual? How did astronomers discover that they are extraordinarily distant and luminous?
2. What evidence showed a link between quasars and galaxies?
3. How are Seyfert galaxies and radio galaxies related to quasars?
4. How can material ejected from quasars appear to travel faster than light?
5. What could power the incredible energy output from active galaxies?
6. Why do many active galaxies emit ultrafast jets of material?
7. What are gamma-ray burststers? How did astronomers discover how far away they are?
Quasars look like stars but have huge redshifts

<table>
<thead>
<tr>
<th>Redshift</th>
<th>Recessional velocity $v/c$</th>
<th>Distance (Mpc)</th>
<th>Distance $(10^9, \text{ly})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.1</td>
<td>0.095</td>
<td>394</td>
<td>1.29</td>
</tr>
<tr>
<td>0.2</td>
<td>0.180</td>
<td>739</td>
<td>2.41</td>
</tr>
<tr>
<td>0.3</td>
<td>0.257</td>
<td>1040</td>
<td>3.39</td>
</tr>
<tr>
<td>0.4</td>
<td>0.324</td>
<td>1310</td>
<td>4.26</td>
</tr>
<tr>
<td>0.5</td>
<td>0.385</td>
<td>1540</td>
<td>5.02</td>
</tr>
<tr>
<td>0.75</td>
<td>0.508</td>
<td>2010</td>
<td>6.57</td>
</tr>
<tr>
<td>1</td>
<td>0.600</td>
<td>2370</td>
<td>7.73</td>
</tr>
<tr>
<td>1.5</td>
<td>0.724</td>
<td>2860</td>
<td>9.32</td>
</tr>
<tr>
<td>2</td>
<td>0.800</td>
<td>3170</td>
<td>10.3</td>
</tr>
<tr>
<td>3</td>
<td>0.882</td>
<td>3520</td>
<td>11.5</td>
</tr>
<tr>
<td>4</td>
<td>0.923</td>
<td>3710</td>
<td>12.1</td>
</tr>
<tr>
<td>5</td>
<td>0.946</td>
<td>3830</td>
<td>12.5</td>
</tr>
<tr>
<td>10</td>
<td>0.984</td>
<td>4040</td>
<td>13.2</td>
</tr>
<tr>
<td>Infinite</td>
<td>1</td>
<td>4190</td>
<td>13.7</td>
</tr>
</tbody>
</table>

This table assumes a Hubble constant $H_0 = 71\, \text{km/s/Mpc}$, a matter density parameter $\Omega_m = 0.27$, and a dark energy density parameter $\Omega_\Lambda = 0.73$ (see Chapter 28). The distance in light-years is equal to the light travel time in years.
Arrows indicate how far each emission line is redshifted from its normal wavelength.
This quasar has such a large redshift \((z = 3.773)\) that these ultraviolet hydrogen emission lines have been shifted to visible wavelengths.
To be seen at such large distances, quasars must be very luminous, typically about 1000 times brighter than an ordinary galaxy.
About 10% of all quasars are strong sources of radio emission and are therefore called “radio-loud”; the remaining 90% are “radio-quiet”.
The number of quasars per volume of space increased during the first 2 billion years after the Big Bang ...

... but has since decreased to near zero.
Some of quasars’ energy is synchrotron radiation produced by high-speed particles traveling in a strong magnetic field.
Quasars are the ultraluminous centers of distant galaxies.
Seyfert galaxies seem to be nearby, low-luminosity, radio-quiet quasars.

Seyfert galaxies are spiral galaxies with bright nuclei that are strong sources of radiation.
Radio galaxies are elliptical galaxies located midway between the lobes of a double radio source.
Relativistic particles are ejected from the nucleus of a radio galaxy along two oppositely directed beams.
"Head" (the galaxy itself)

"Tail" (a radio-emitting jet)

"Tail" (a radio-emitting jet)

Direction of the galaxy's motion
Seyferts and radio galaxies bridge the gap between normal galaxies and quasars.

(a) A quasar jet at radio wavelengths...  
(b) ...and at X-ray wavelengths
Blazars are bright, starlike objects that can vary rapidly in their luminosity. They are probably radio galaxies or quasars seen end-on, with a jet of relativistic particles aimed toward the Earth.
Quasars, blazars, Seyferts, and radio galaxies are active galaxies

- Quasars, blazars, and Seyfert and radio galaxies are examples of active galaxies.
- The energy source at the center of an active galaxy is called an active galactic nucleus (AGN).
- Rapid fluctuations in the brightness of active galaxies indicate that the region that emits radiation is quite small.

**Table 27.2: Properties of Active Galactic Nuclei (AGNs)**

<table>
<thead>
<tr>
<th>Object</th>
<th>Found in which type of galaxy</th>
<th>Strength of radio emission</th>
<th>Type of emission lines in spectrum</th>
<th>Luminosity (watts)</th>
<th>Luminosity (Milky Way Galaxy = 1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blazar</td>
<td>Elliptical</td>
<td>Strong</td>
<td>Weak (compared to synchrotron emission)</td>
<td>$10^{38}$ to $10^{42}$</td>
<td>10 to $10^5$</td>
</tr>
<tr>
<td>Radio-loud quasar</td>
<td>Elliptical</td>
<td>Strong</td>
<td>Broad</td>
<td>$10^{38}$ to $10^{42}$</td>
<td>10 to $10^5$</td>
</tr>
<tr>
<td>Radio galaxy</td>
<td>Elliptical</td>
<td>Strong</td>
<td>Narrow</td>
<td>$10^{36}$ to $10^{38}$</td>
<td>10 to $10^5$</td>
</tr>
<tr>
<td>Radio-quiet quasar</td>
<td>Spiral or elliptical</td>
<td>Weak</td>
<td>Broad</td>
<td>$10^{38}$ to $10^{42}$</td>
<td>10 to $10^5$</td>
</tr>
<tr>
<td>Seyfert 1</td>
<td>Spiral</td>
<td>Weak</td>
<td>Broad</td>
<td>$10^{36}$ to $10^{38}$</td>
<td>0.1 to 10</td>
</tr>
<tr>
<td>Seyfert 2</td>
<td>Spiral</td>
<td>Weak</td>
<td>Narrow</td>
<td>$10^{36}$ to $10^{38}$</td>
<td>0.1 to 10</td>
</tr>
</tbody>
</table>
**Superluminal Motion**

**View from Earth**

- **First pulse of light** reaches Earth in 2010.
- **Second pulse** of light is emitted 6 years later, but has 4 fewer light-years to travel—reaches Earth 2 years after the first pulse, in 2012.

**To Earth**

- **Blob at A**
  - 5 light-years
- **Blob at B**, 6 years later
  - 3 light-years

**Actual speed of blob** = \( \frac{5}{6} c \)

**Apparent speed of blob** = \( 1.5c \)
1. An object 1 light-year across emits a sudden flash of light.

2. The first light that we receive comes from A (the part of the object nearest to Earth).

3. The light from B (the center of the object) has to travel an additional $\frac{1}{2}$ light-year to reach Earth, so we see this light $\frac{1}{2}$ year later than the light from A.

4. We see the light from C (the far side of the object) $\frac{1}{2}$ year later than the light from B and 1 year later than the light from A. Hence we see the sudden flash of light spread over a full year.
Supermassive black holes are the “central engines” that power active galactic nuclei

- The evidence suggests that an active galactic nucleus consists of a supermassive black hole onto which matter accretes.
- As gases spiral in toward the supermassive black hole, some of the gas may be redirected to become two jets of high-speed particles that are aligned perpendicularly to the accretion disk.
1. Material in an accretion disk spirals inward toward the black hole.

2. Most inward motion halts here due to conservation of angular momentum, giving the accretion disk a sharp inner edge.

3. Only part of the infalling material reaches the black hole.
Quasars, blazars, and radio galaxies may be the same kind of object seen from different angles.
An observer sees a radio galaxy when the accretion disk is viewed nearly edge-on, so that its light is blocked by a surrounding torus.
• At a steeper angle, the observer sees a quasar.
• If one of the jets is aimed almost directly at the Earth, a blazar is observed.
Gamma-ray bursters produce amazingly intense flashes of radiation

- Short, intense bursts of gamma rays are observed at random times coming from random parts of the sky
- The origin of short-duration gamma-ray bursters is unknown
By observing the afterglow of long-duration gamma-ray bursters, astronomers find that these objects have very large redshifts and appear to be located within distant galaxies.
The bursts are correlated with supernovae, and may be due to an exotic type of supernova called a collapsar.
Jargon

- accretion disk
- active galactic nucleus (AGN)
- active galaxy
- blazar
- collapsar
- double radio source
- Eddington limit
- gamma-ray burster
- head-tail source
- nonthermal radiation
- polarized radiation
- quasar
- radio galaxy
- radio lobes
- Seyfert galaxy
- superluminal motion
- supermassive black hole
- thermal radiation