Quasars: Back to the Infant Universe
What is a quasar? What spectral features tell us quasars are very redshifted (very distant)? What spectral features tell us they are composed of hot gas orbiting something?

Quasars appear extremely bright. Is this because they’re close to us or because they’re intrinsically luminous?

What observations of quasars tell us they are small?

What are Seyferts and Radio Galaxies? What is at the center of a galaxy that powers a quasar?

Why are there few quasars close to us? Could quasars ever have existed close to us? Why is gas important?

What is the merger cycle that drives quasars? Why is a quasar a phase in time rather than an object in space?
A Very Strange Star

- 3C 273 is a very powerful radio source
- Astronomer Maarten Schmidt took optical images of it in 1963 and found it looked like a normal blue star
- He also took a spectrum and found it had very odd spectral lines
- It’s clearly not a star
Quasar Spectra

When a spectrum is taken, a quasar looks nothing like a star.
The Mystery of Quasars

- 3C 273 is a quasar (QUASi-stellAR object)
- Its distance is \(~2.4\) billion light years away
  - The Andromeda galaxy is \(~1000\) times closer than this
- The apparent magnitude of 3C 273 is \(~12.9\)
  - It is visible in a small telescope
- It therefore must be incredibly bright
  - Its luminosity is equal to about 2 trillion Suns, or about 100 times the entire Milky Way!
Quasar Spectra

- Power-Law (not blackbody) continuum indicates a hot, but not single-temperature central source
- Broad emission lines indicate very hot, rapidly orbiting gas

Quasar Spectrum from Vanden Berk et al. (2001)
Quasar Variability Indicates they have a Small Size

Time of rise and fall in quasar brightness tells us its maximum size (= *time to vary* $\times$ *the speed of light*)
Quasars Live In The Centers of Distant Galaxies

- More than 500,000 quasars are known
- Almost all quasars are farther than three billion light-years away
- Galaxies hosting quasars often appear irregular, as if they recently merged with another galaxy
Quasars, In Brief...

- Quasars are at *truly* “astronomical” distances
- Great distances - must be very luminous
- Quasars are highly variable on short timescales
- Are at the centers of ( ) galaxies
- Quasars’ spectra suggest very, very hot gas rapidly orbiting *something*
Are there Quasars near us in the Universe?

- There are now no quasars in the nearby Universe.
- But there are some very energetic galaxies (about 1% of all galaxies)
  - Very bright nuclei
  - Often, energetic jets from the nucleus
- Called active galaxies
- Types of active galaxies
  - Seyfert galaxies
  - Radio galaxies
- Seyferts are basically just less energetic quasars
Radio Galaxies

- Galaxies that emit large amounts of radio waves
- Radio emission come from lobes and jets on either side of the galaxy, not from the galaxy itself

Cygnus A

lobe

active galactic nucleus

hot spot

visible galaxy

jet

lobe

100,000 light-years
M87’s Blow Torch

- M87 is the closest Giant Elliptical Galaxy to our Milky Way (~ 60 million light years away in the Virgo Cluster)
- M87 has a huge radio jet, about 5000 light-years long
What is the Power Source for Quasars and Active Galaxies?

- Gas falling onto a super massive black hole is the only way to explain quasars
  - Up to ~1000 solar masses of material is swallowed by the BH in a quasar each year
- As a piece of matter falls into the black hole, ~25% of its mass ($E=mc^2$) is converted into energy
- Compare this to fusion in the Sun where ~0.7% of the mass is converted to energy
Do Supermassive Black Holes Really Exist? **YES!**

Active supermassive black holes (AGN) in the centers of nearby galaxies...

Orbital speeds of the gas at the center of NGC 4261 indicate a black hole with a mass of 270 million $M_\odot$.

Orbital speeds of the gas at the center of M87 indicate a black hole with a mass of 6.5 billion $M_\odot$. 
Orbits of stars near the Galactic center prove there is an object ~ 4 million times the mass of the Sun at the center of our Galaxy. This object is in a region that is smaller than a neutron star...only a supermassive black hole can explain this.

What About Supermassive Black Holes in Non-Active Galaxies?
Where are all the quasars now?

- Supermassive black holes probably exist in almost all if not all galaxies’ cores.
- There are no really bright quasars nearby, i.e., at this time in the history of the Universe.
- In the past, quasars were more common than now.
- As the Universe aged, the quasars have disappeared.
  - Quasars have turned off as the Universe has aged.

### Table 16-1: Galaxy and Quasar Luminosities

<table>
<thead>
<tr>
<th>Object</th>
<th>Luminosity (watts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td>$4 \times 10^{26}$</td>
</tr>
<tr>
<td>Milky Way Galaxy</td>
<td>$10^{37}$</td>
</tr>
<tr>
<td>Seyfert galaxies</td>
<td>$10^{36} - 10^{38}$</td>
</tr>
<tr>
<td>Radio galaxies</td>
<td>$10^{36} - 10^{38}$</td>
</tr>
<tr>
<td>Quasars</td>
<td>$10^{38} - 10^{42}$</td>
</tr>
</tbody>
</table>
It’s Just a Phase They’re Going Through

- All galaxies may have passed through a quasar-like stage earlier in time.
- Mergers between large galaxies channel gas to the black hole at a galaxy’s center, triggering a quasar phase until the gas runs out.

Galaxy evolution from spiral to quasar to elliptical galaxy via an interaction/merger.
Next Time

The Distance Ladder