Notes about the exam
Average 58% - will be curved

• Study my notes
• Read the book
• Study my notes II
• Ask me questions
• …tell me where are you having difficulties…
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 bursters? How did astronomers discover how far away they are?
Quasar

- Ordinary star emits primarily is UV, visible and IR (related to Temperature of the star)
- Ordinary Galaxies-same
- Objects such as 3C 273 emits thousands of times the radiation output of an ordinary galaxy with a jet that extends hundreds of thousand of light years
Quasars and Active Galaxies

- Quasars are intimately related to *active galaxies* (whose luminosity fluctuate substantially over a period of months, weeks)
- Quasars and active galaxies emit their intense radiation continuously but from time to time there is a flashes of high-energy gammas rays (Gamma-ray bursters)

Look at the weblink on freedman
Quasars

- The development of radio astronomy in mid twentieth century that revealed Quasars
- Baade & Minkowski ‘51 realized that At the center of Cygnus A there Was a galaxy with EMISSION LINEs
  - (normal galaxies have absorption Lines)
  - (absorption lines: due to the atmosphere of stars that constitute the galaxy)
  - (they also look at the emission lines Redshift- high redshif!)
For Cygnus A the redshift was $z=0.056$ corresponding to a velocity of 16,000 km/s. If Cygnus A participated in the Hubble flow as clusters of galaxies, this velocity will correspond to a distance of 230 Mpc from Earth (VERY DISTANT!).

Despite the distance, the radio waves can be picked up by amateur astronomers, so Cygnus A must be very luminous.

In fact, Cygnus A has $10^7$ time more luminosity than an ordinary galaxy such as MW!
In 1960 Allan Sandage discovered a “star” at the location of the radio source designated 3C 48.

- Ordinary stars are not strong sources or radio emission.
- Like Cygnus A, it had emission lines!
Two years later astronomers discover a similar starlike optical counterpart to radio Source 3C 273.

In 1963 M. Schmidt noticed that the emission lines were the Four Balmer lines of hydrogen but shifted $Z=0.158$; so its 620 Mpc away.

After that, Greenstein & Matthews identified the spectral lines of 3C 48 as in redshift $Z=0.367$ at 1300Mpc.

The spectrum of 3C 273:
The arrows indicate how far the lines are redshifted from its normal wavelength.
Because their strong radio emission and starlike appearance 3C 48 and 3C 273 were dubbed Quasi-stellar radio sources or QUASARS

After the first quasars were discovered Many similar, high-redshift, starlike objects were found that emit Little or no radio radiation -> those are called QSOs

Today Quasars is often used to include both types:

Only 10% of quasars are “radio-loud”!
More than 100,000 quasars are now known! They all look like stars and all have large redshifts ranging from 0.06 to 5.8.

Most quasars have redshift of 0.3 or more (so they are 1000 Mpc away).

Example: quasar PC 1247+3406 has a redshift of $z=4.897$.

Example: quasar PKS 2000-030. The UV hydrogen emission lines have been shifted to visible wavelengths.
Quasars look like stars but have huge redshifts

These redshifts show that quasars are several hundred megaparsecs or more from the Earth, according to the Hubble law.

The distance that we are calculating is light travel time or the distance that light traveled to reach us from the quasar (how many years in the past you are looking when you view the object).

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<th>Recessional velocity</th>
<th>Distance</th>
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This table assumes a Hubble constant $H_0 = 71$ 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.
There are no quasars with small redshifts
There are no nearby quasars - the nearest is ~ 250 Mpc from Earth.…the absence of nearby quasars means that There have been no quasars from 800 million years…. 
Quasars are Extinct

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.

Now
What are Quasars?

• They cannot be just simple galaxies because their spectra are Totally different: emission lines (while spectrum of galaxy is Dominated by absorption lines)

• Quasars also emit much more of their light in UV than stars Or galaxies.

• Quasars turn out to be ultraluminous objects located at the Center of remote galaxies
Quasars Luminosity

For example 3C 273 has a luminosity of $10^{40}$ watts (equivalent to $2.5 \times 10^{13}$ suns)

Generally, quasar luminosity range from $10^{38}$ watts - $10^{42}$ watts
(for comparison a typical large galaxy shines with $10^{37}$ watts)

Look in web link 27.5 on the debate by Halton C. Arp on the “projection effect”
…made him challenge the Hubble law and say high-redshift quasars seem
To be located in low-redshift galaxies…

What ended the debate were observations showing that quasars are associated
with remote galaxies

In 1980’s astronomers show that the fuzz around quasars show stellar absorption
And that the absorption lines of the stars have the same redshift as the
Quasar’s emission lines
(a) Quasar PG 0052 +251 is located at the center of a normal spiral galaxy at a Redshift of $z=0.155$
(b) The galaxy that hosts quasar PG 1012+008 ($z=0.185$) is in the process of Merging
( c ) A long tail of dust and gas extends upward in the image of quasar PG 0316-346 (presumably formed when the quasar’s host galaxy collided with a second Galaxy)
Location of quasars

- Nearby radio-quiet quasars ($z < 0.2$) tend to be located in spiral galaxies
- Radio-loud quasars as well as more distant radio-quiet quasars tend to be located in ellipticals
- A large percentage of the host galaxies have distorted shapes (peculiar shapes)—many have companion galaxies (suggesting a link between collisions or merging and the quasar)
- Clues to what are quasars come from a class of galaxies that are intermediate in luminosity between quasars and normal galaxies
“Missing links” between quasars and ordinary galaxies were actually discovered before quasars....

• Carl Seyfert (in 1943) studies spiral galaxies that show signs of intense and violent activity
• Like quasars, the nuclei of these galaxies have strong emission lines. They are called Seyfert galaxies.

A Seyfert Galaxy
A few percent of the most luminous spiral galaxies are Seyfert. These galaxies range in luminosity between $10^{36} - 10^{38}$ watts (so they are as bright as faint quasars).

In fact there is no sharp dividing line between the properties of Seyferts and those of quasars.

Like radio-quiet quasars Seyfert tend to have only weak radio emission. And like quasars, some Seyferts are members of interacting pairs of exhibit the vestiges of mergers or collisions.

Seyfert galaxies seem to be nearby, low-luminosity, radio-quiet quasars.
While Seyfert galaxies resemble dim, radio quiet quasars, certain elliptical galaxies called radio galaxies (because of their strong radio emission) are like dim radio-loud quasars.

(a) The giant elliptical galaxy M87
(b) A shorter exposure reveals M87’s jet
Most of the light from the central regions of M87 is **thermal radiation** (with a spectrum like blackbody) (this spectrum of thermal radiation only depends on the object’s temperature—there are also absorption lines in the spectrum which indicates that this radiation is due to stars crowded in the galaxy’s center). But the light from the jet is **nonthermal radiation** (this energy is NOT due to random thermal motion and has a very different spectrum that thermal radiation).
Some of quasars’ energy is synchrotron radiation produced by relativistic particles traveling in a strong magnetic field.

Blackbody always has a hump - by contrast the nonthermal spectrum of synchrotron Radiation shows a steady decline with frequency - so the presence of synchrotron Radiation coming from M87’s jet indicate that relativistic particles are being ejected From the galaxy’s nucleus and encountering magnetic field.
The radiation of the jet is non-thermal and polarized radiation (which means that Electric fields of the waves are oriented in a specific direction)

By contrast thermal radiation is unpolarized (consist of waves whose electric fields Are oriented at random angles)
Radio galaxies are elliptical galaxies located midway between the lobes of a double radio source.

The spectrum and polarization of the Radio-frequency emission from the Lobes of a double radio source bears the Characteristic of a synchrotron Radiation.
Head-tail sources: the source is the “head” and the two long Radio-emission streams are the “tails”

Head-tail source NGC 1265 moving At a high speed (2500 km/s) through the Perseus cluster of galaxies
Seyfert galaxies and radio galaxies share many properties with The more remote, more luminous galaxies

The key difference is that we see many Seyferts and radio galaxies that
Are relatively close to us (recent past),

Whereas we see quasars at great distances (remote past)

Thus, quasar-like objects have not completely disappeared from the
Universe, but those who remain in the present-day universe

Seyfert and radio luminous galaxies are a pale shadow of the intensely Luminous quasars
Jet Emanating from High-redshift quasar

(a) A quasar jet at radio wavelengths...
(b) ...and at X-ray wavelengths

Quasar at z=4.3 (distance of 3700 Mpc) - quasar at a time
When the universe was only 10% of its
Present age
Key Words of Today

• active galaxy
• double radio source
• head-tail source
• nonthermal radiation
• polarized radiation
• quasar
• radio galaxy
• radio lobes
• Seyfert galaxy
• thermal radiation