Quasars

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What are Quasars?

- The sun shines with nuclear fusion energy: converts 0.7 percent of its mass into energy over 10,000,000,000 years
- A luminous quasar converts 100 percent of the mass of our sun into energy EVERY year!
- Quasars live in the centers of galaxies
- The gas orbiting a quasar moves at a fair fraction of lightspeed, implying the quasar has a lot of gravity.
- A number of pieces of evidence suggest the quasar is no larger than a single solar system, even though it is brighter than an entire galaxy.

Context

- In the 1920s it was finally demonstrated that the faint spiral and elliptical nebulae were actually external galaxies
- Our horizons expanded to study objects millions of light years away
- Since then, we have found galaxies hundreds of times more distant still
- It is in the centers of these distant galaxies that the bright quasars may be found.

The Distance Scale

- Size of the Earth: 40 milliseconds (8000 miles)
- Size of Jupiter: 0.4 seconds (75000 miles)
- Distance to the Moon: 1.25 seconds (236000 miles)
- Size of the Sun: 4.5 seconds (900,000 miles)
- Distance to the Sun: 8 minutes (93 million miles)
- Distance to Neptune: 4 hours (3000 million miles)
- Distance to Proxima Cen: 4 years (25000 million million miles)
- Size of Milky Way galaxy: 80000 years (500,000,000,000,000,000,000 miles)
- Distance to the Andromeda galaxy: 2 million years
- Distance to the Virgo Cluster: 80 million years
- Distance to the farthest known galaxies: 10 billion years

The Secrets of Starlight

- A prism separates a beam of light into its component colors, as nature does with a rainbow. We can measure how much of each color is present.
- Glowing hot gas gives out light of very specific colors ('lines') whose pattern depends on the elements making up the gas and the speed with which the gas is moving (e.g. yellow sodium street lights).
- The atmospheres of stars and the clouds between the stars contain hot gas giving out light in this way. So we can figure out what the distant stars are made of and how fast they are moving.
- Quasar light is distinguished by the strong continuum light and the presence of broad lines in the spectrum.

The Mystery of the Seyfert Galaxies

- Studies of galaxies reveal that the stars and gas in them orbit around the center of the galaxy at a few hundred kilometers a second (about half a million MPH!)
- In 1917 V. Slipher discovered that the nucleus of the galaxy NGC 1068 contained gas emitting broad spectral lines.
- Interpreting these lines as a doppler effect means that the gas is moving at thousands of km per sec - much faster than in a normal galaxy.
- In 1943 Carl Seyfert pointed out that NGC 1068 was one of a whole class of galaxies with strange nuclei. These 'Seyfert nuclei' are tiny compared to their 'host galaxy' but are responsible for a substantial fraction (10 to 50 percent) of its light.
- The Seyfert nuclei are the most common, nearby, and least dramatic examples of the objects we now call **Active Galactic Nuclei** or '**Quasars**'.
- In 1963 the bright quasars 3C 48 and 3C 273 were discovered. These nuclei are so much brighter than their host galaxies that it took 15 years to get a picture of the underlying starlight in the surrounding galaxy. This meant it took a long time before we were sure that Seyferts and Quasars were extremes of the same phenomenon. The discovery of 'missing links' like the galaxy Fairall 9, where the quasar nucleus is only just brighter than the surrounding galaxy, helped clarify the situation.

Quasars are weird!

- Quasars emit all kinds of light - radio, infrared, visible, ultraviolet, X-rays, gamma rays
- Quasars are as luminous as a trillion stars, yet -
- Quasars change their brightness dramatically in only a year.

Clues to the nature of quasars

- Varies in brightness in a few months $\rightarrow$ less than a lightyear in size
- Gas velocities large $\rightarrow$ lots of mass in a small region (more than 100 million solar masses)
- Maser sources give accurate measurements of gravity in some nearby Seyferts, proving that many millions of solar masses are present in a volume much less than a lightyear across.
- Luminosity enormous for extended period of time $\rightarrow$ lots of mass being converted into energy (solar mass per year for at least ten million years)
- Radio quasars have narrow jets millions of lightyears long $\rightarrow$ quasars last a long time AND they remember a single direction for a long time (something spinning?)
- Radio jets are matter moving at relativistic speed $\rightarrow$ Strong accelerating forces (magnetic fields?) and strong gravity?

- Conclusion: accretion of matter onto a rapidly spinning supermassive black hole is the most likely scenario.

The model

- At the center of the quasar lurks a rapidly spinning supermassive black hole
- Gas falls towards the hole but misses: it forms an accretion disk and slowly trickles into the hole
- The strong gravity of the black hole, combined with friction in the disk, causes the matter in the accretion disk to release huge amounts of energy.
- Some of the matter trickling into the hole again misses, and is shot out at relativistic speeds along the poles, making the radio jets
- Thick gas clouds around the hole absorb the radiation, making the central disk invisible from some directions
- Thin gas clouds are ionized, reradiating the energy in emission lines.

The many types of quasar

- Radio-loud versus radio-quiet: some quasars have the radio jets, some don't
- Quasars versus radio galaxies: sometimes we see the optical emission, sometimes not.
- Quasars and Seyferts: some quasars are thousands of times more luminous than others
- Seyfert Type 1 and Seyfert Type 2: some Seyferts hide their cores behind thick gas clouds.
- BAL (Broad Absorption Line) quasars: some quasars have large amounts of outflowing gas.
- Spectral differences: Fe II loud, weak bump, IR weak, etc, etc...

History

- 1917 Slipher discusses broad lines in galaxies
- 1943 Seyfert's paper
- 1950s Discovery of radio galaxies
- 1963 Radio-loud quasars discovered
- 1965 Radio-quiet quasars discovered
- 1969 Lynden-Bell accretion disk theory
- 1978 X-rays common in quasars
- 1979 Twin quasar discovered
- 1980 First good radio images
- 1985 Unification theories of quasars
- 1995 Emerging consensus?

Fun quasar facts

- Quasar evolution
- What if our galaxy went quasar?
- Superluminal motion
- Gravitational lensing