Quasars: Probes of the distant universe

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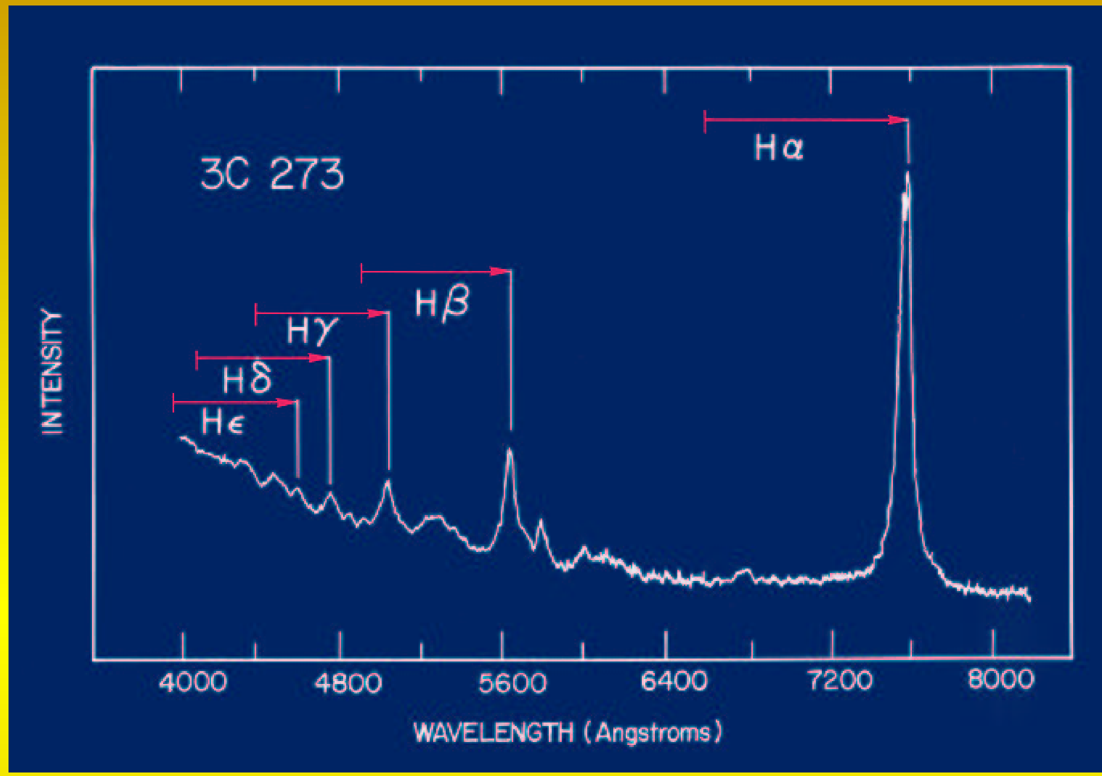
http://wopr.caltech.edu/~mph/words/fleet-jun02.pdf

Quasars are among the most luminous objects in the universe (about $10^{13}\ L_\odot$, *vs.* $10^{10}\ L_\odot$ for normal galaxies).

Because they are so luminous, they can be studied at great distances, and serve as probes of the distant (and hence early) universe.

Quasars are generally compact, and look like normal stars in images. But some of them can be detected with radio telescopes, which is unusual for stars.

Maarten Schmidt observed one of these "radio stars" with an optical spectrograph at Palomar in 1963. Spectrographs use a prism or grating to record how bright an object is at every wavelength, or color. Different elements result in emission or absorption at specific wavelengths, so spectroscopy allows you to learn about the elements in an object.



Schmidt and his colleagues could not make any sense of the 3C 273 spectrum; none of the lines looked familiar. Schmidt eventually realized that they came from Hydrogen, the most common element in the universe. But they were in the wrong place!

Schmidt concluded that the object was *redshifted* because of the expansion of the universe, but he was surprised, because 3C 273 was far brighter than any galaxies at that distance!

That meant that 3C 273 was very far away, and hence much more luminous than stars or even galaxies.

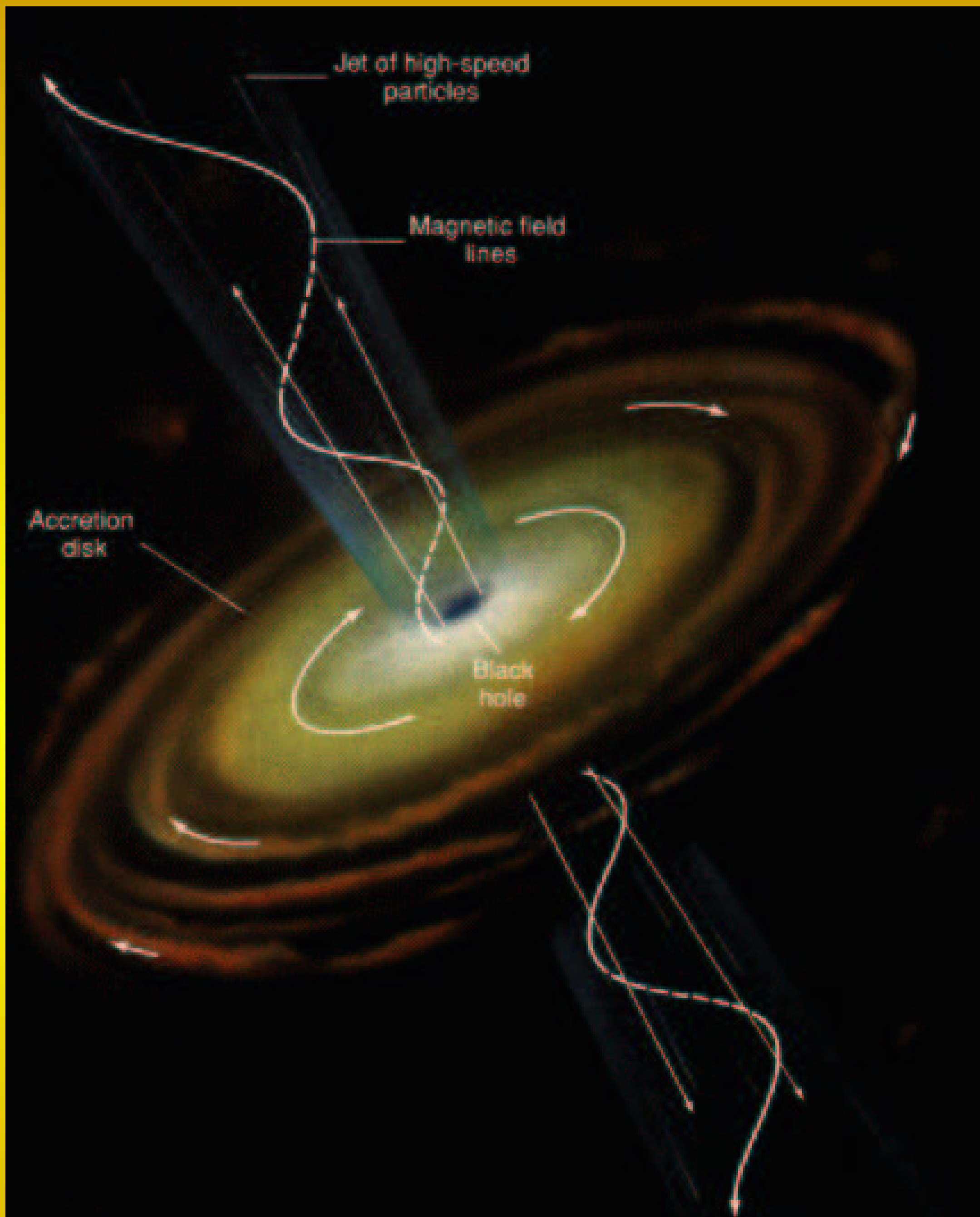
In time, it was found that most quasars are variable, growing brighter and fainter over time. This variability, combined with the speed of light, sets a limit on how large the emitting source can be.

Variability on roughly 30-day timescales implies an emission region smaller than 0.1 parsec. (A parsec is about 3.26 light years, or 3.1×10^{13} km.)

For comparison, galaxies are about 20,000 parsecs across. So quasars produce the light of a thousand galaxies from a region millions of times smaller than a single galaxy!

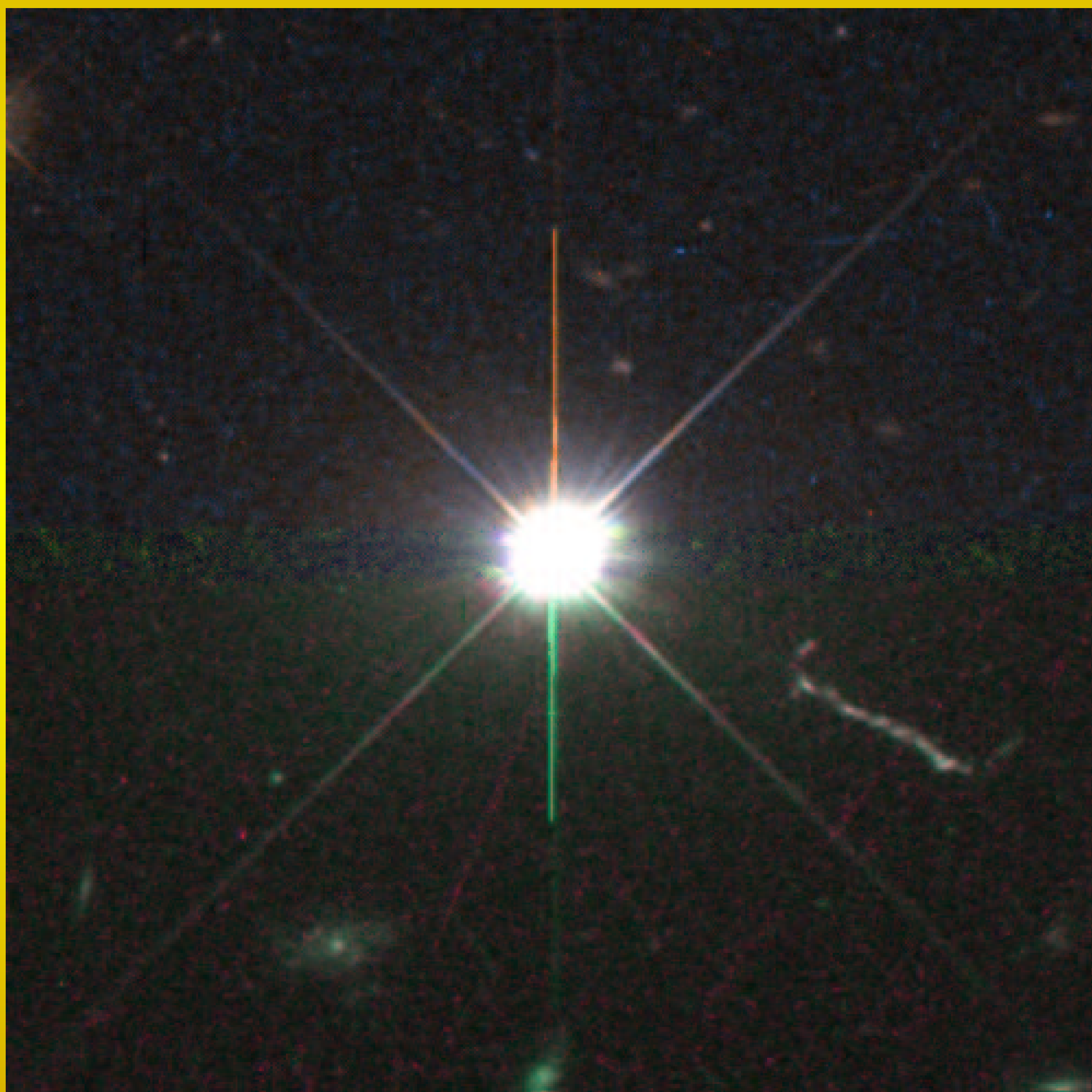
What can produce such power? The only viable answer has been matter falling into a supermassive black hole (10^8 $M_\odot$ and up). No other known process can produce so much power in so little space.

As gas and dust spiral into the black hole, viscous forces heat the accretion disk, and it radiates a great deal of power.



Note the jet which arises from material being ejected along the magnetic field lines.

Such jets are visible in nearby quasars, including 3C 273 itself:



In recent years, astronomers have been able to measure the masses of these supermassive black holes more directly, by seeing how quickly stars near the centers of nearby active galaxies (quasars and their kin) orbit the center of the galaxy.

An astonishing result: Not only do active galaxies have the $10^8\ M_\odot$ (and up) black holes at their centers, but so do all of the "normal" galaxies which have been studied, including our own Milky Way!

Also astonishing is that the mass of the black hole is closely related to the mass and dynamics of the whole galaxy, even though the black hole's contribution is tiny (0.1%).

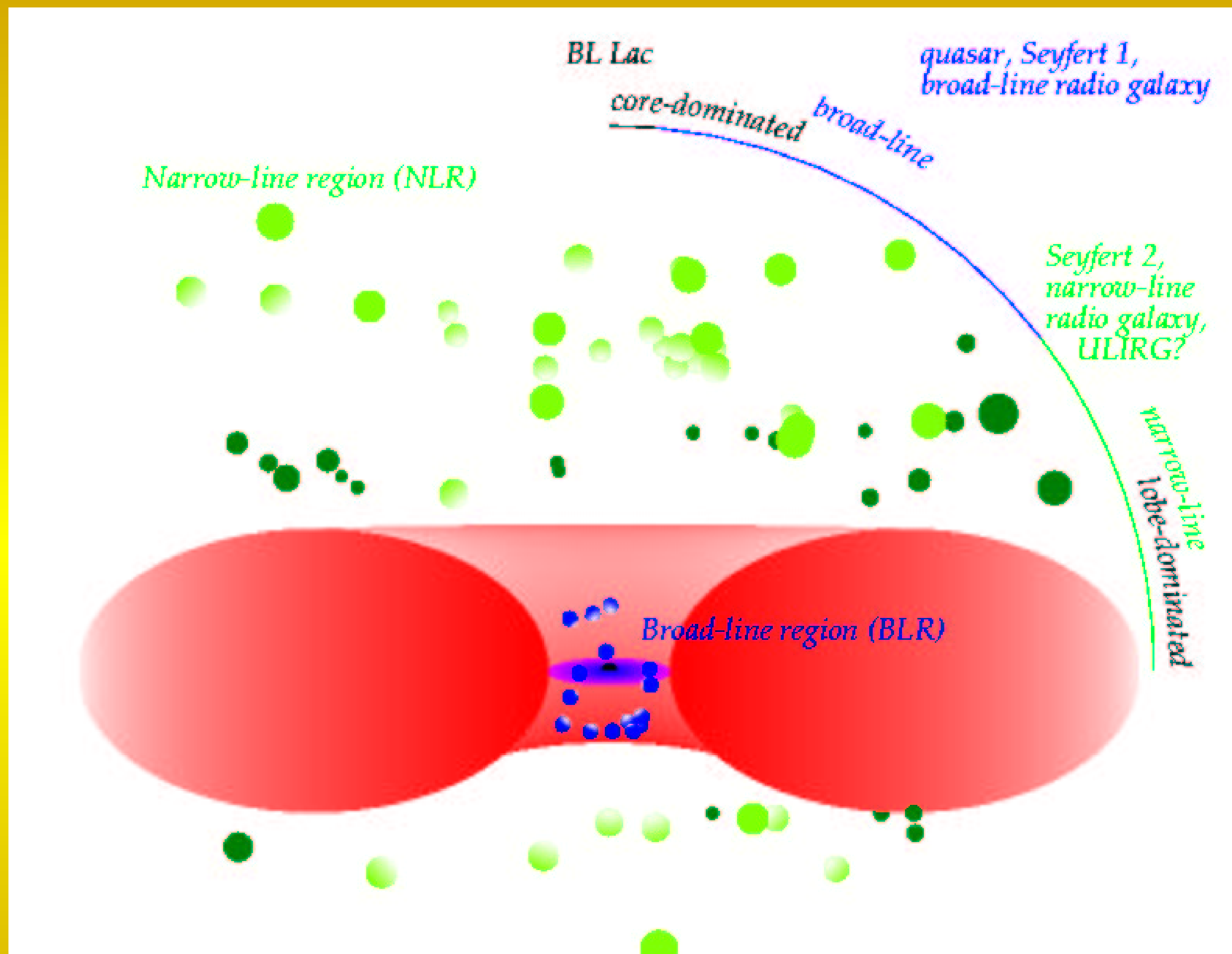
Important open questions:

- How do the supermassive black holes form?
- How are they related to the formation of the whole galaxy?
- If all galaxies contain supermassive black holes, does that mean they all go through an active phase?
- What turns the active phase on and off?

What about other types of active galactic nuclei (AGN)?

For a long time, astronomers have known that there are other types of active galaxies whose spectral or other properties don't match quasars. (For example, some have narrow emission lines instead of broad ones, or they are not as bright, or they had visible host galaxies when no known quasars did, or...)

They all had different names (Seyfert 1, Seyfert 2, LINER, BL Lac, radio galaxy, etc.) but were presumably all powered in similar ways. In fact, their differences can generally be explained using the unification model for AGN.

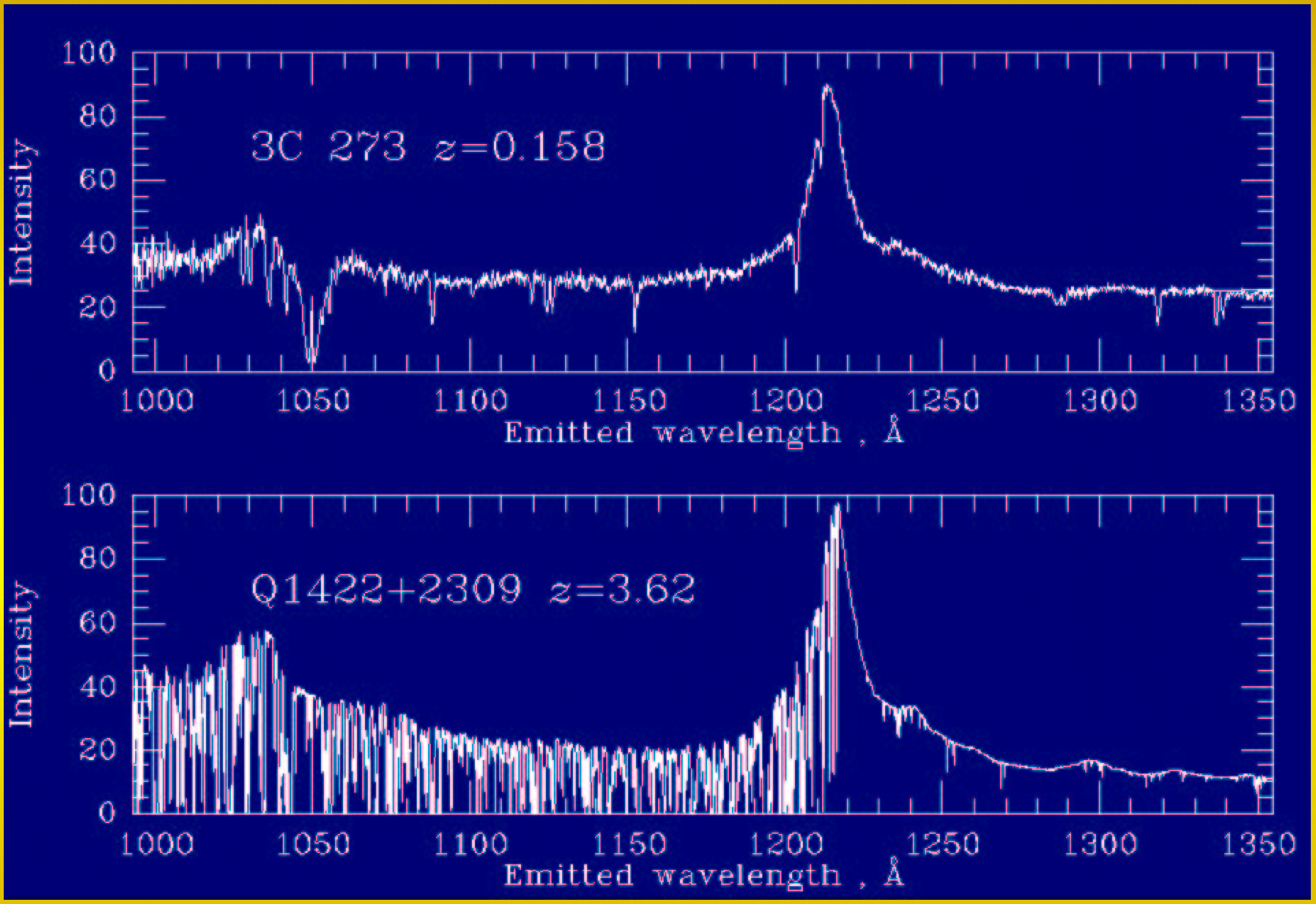


(Figure: Chris Simpson)

Clever quasar tricks: The forest and the trees

Quasars emit a lot of their light in the ultraviolet; some of this light can be absorbed by neutral hydrogen gas to increase the energy of its electron. The light that is absorbed has a specific wavelength, 1216 Å. (1 Å $= 10^{-10}$ m.) This wavelength is called Lyman-α ("Lyman alpha").

Most of the hydrogen in the universe is ionized (stripped of its electron), and hence does not absorb this light. But, if there is a blob of neutral hydrogen between us and a quasar, we will see an absorption line in the quasar's spectrum, showing us the redshift of the neutral gas. This "forest" of absorption lines is called the "Lyman-α forest."



(Figure: Bill Keel.)

One obvious conclusion from the spectra is that neutral hydrogen used to be much more common (at $z = 3$) than it is today (at $z = 0$).

Indeed, in the past two years, astronomers have started to find evidence in the spectra of the most distant quasars ($z = 6$) that the hydrogen was not yet ionized. This has long been expected, but only now can we observe this era directly. Studies of the "epoch of reionization" will provide insight into early galaxy and star formation.

Conclusions

Quasars are extremely luminous objects powered by matter heating up as it falls onto a supermassive black hole at the center of a galaxy. They can provide considerable information about the distant (early) universe, including:

- Galaxy formation
- The gas–galaxy connection
- The epoch of reionization

Excellent books about Palomar

First Light by Richard Preston (author of *The Hot Zone*). A first-person account of observing on the 200-inch with Maarten Schmidt and collaborators and on the 18-inch Schmidt telescope with Gene and Carolyn Shoemaker. A fun read.

The Perfect Machine by Ronald Florence. A detailed, impressive history of the design and construction of the 200-inch telescope. Heavier, but fascinating.

Both books are in print and should be easy to purchase.