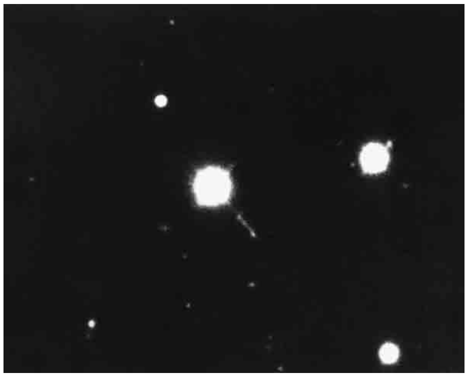
MOUNT HOLYOKE COLLEGE

i42

Final Problems 2004 Spring Semester

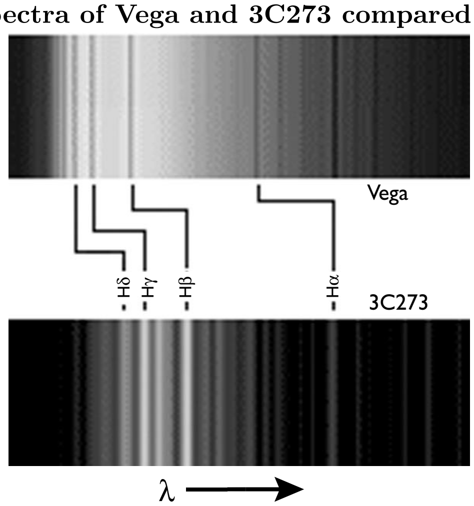
1. A quasi-stellar radio source



This is a very high magnification photograph of a very small region of the sky. Except for the just-barely noticeable jet extending from the lower right, the object at the center of this photogaph looks just exactly like a normal star. But in the early 1960s it was found that this position on the sky coincides exactly with a source of radio frequency electromagnetic waves with $\nu \sim 10^9$Hz: a *radio source* masquerading as a *star*, now calles a *quasi-stellar radio source* or, for short, a *quasar*.

→ What is the wavelength of such radio waves?
→ How do these wavelengths compare to those of the visible light used to make the above photograph?

2. Spectra of Vega and 3C273 compared

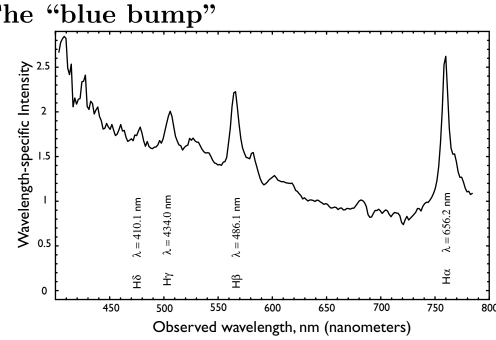


In this next photograph, there are two spectra, taken with the same telescope and spectrograph, and printed to the same scale. The top spectrum was produced by light from the bright star Vega. Vega has a surface temperature which is very nearly optimal for displaying an absorption line spectrum of Hydrogen — the "Balmer Lines" which correspond to an H-atom making a quantum jump from the $n = 2$ level to some higher level. About 1962 Maarten Schmidt discovered what is diagrammed in this picture — that the *emission lines* in the spectrum of 3C273 correspond to these hydrogen lines shifted to longer wavelengths ("redshifted") by about 16% — i.e.,

$$\frac{\Delta\lambda}{\lambda} = 0.16\,.$$

→ Bearing in mind that this was by far the largest such redshift that had ever been observed at that time, what did it tell astronomers about the distance to 3C273, compared to any other object in the known universe?
→ Explain.

3. The "blue bump"



In this view, the spectrum of 3C273 is shown as a graph, rather than an image, and with a vertical scale — intensity — which is quantitatively accurate. Notice that the emission lines are superimposed upon a background which is increasing toward the shorter wavelenths, and is continuing to rise at the left edge of the graph. This feature of quasar spectra has been dubbed "the blue bump".

→ Compared to photons in the emission-line spectrum, are the photons of the "blue bump" more or less energetic?

Remember (or refresh your recollection by referring back to the quote from Einstein's 1905 paper) that one of the problems Einstein solved by inventing the photon was something called "Stokes' rule".
→ What does Stokes' rule have to say about the possibility of of the "blue bump" energizing the emission lines in the quasar spectrum?

— !!! Continued on Back !!! —

4. Origin of the "blue bump"

Most quasar specialists think that the "blue bump" is produced in the immediate vicinity of a super-massive black hole that resides at the very center of a galaxy. As gas is "sucked into" this black hole, it is compressed and heated to extremely hot temperatures — certainly hotter than the surfaces of any normal stars. (Note that this very hot gas is *close to* but not *inside* the black hole!)

→ How can we be sure that, if any such very large mass of very hot gas exists at the center of a galaxy, it would emit blue and ultraviolet light?

→ How does this suggest an origin for the "blue bump"?

5. The path of a photon

Working further out into space from the black hole, and the region of very hot gas surrounding it, quasar astronomers reason that there must eventually be a region in which the gas is much cooler.

→ Bearing in mind what you know about how "the three types of spectra" can be produced, can you figure out a path whereby the light originating near the black hole can reach a region of cooler gas, and energize the *hydrogen emission-line spectrum* so famously observed by Maarten Schmidt?
→ Explain it all in a few sentences and a diagram.

6. How would it look?

Roughly sketch in the boundaries of your eyes' RGB cone systems on the graph of question 3.

→ Think about the stimulation of each of these three systems in your eye, and try to figure out approximately the color which this famous quasar would appear *if* you had a large enough telescope.
→ Explain your reasoning.