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What Causes a Quasar?

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How do quasars shine? What causes their enormous luminosities, which can be a thousand times greater than the luminosity of the entire Milky Way galaxy? How is all of this punch packed into a region no larger than our own solar system?

The Hubble Space Telescope was designed, in part, to help answer these questions. Based upon previous ground-based observations and upon schematic theoretical calculations, a consensus view has developed over the last thirty years that quasars involve massive black holes in the centers of bright galaxies. These voracious black holes gobble up gas and stars from their galactic hosts. Many authors have suggested that the brighter quasars are located in brighter galaxies, that radio-loud quasars reside in elliptical host galaxies, and that radio-quiet quasars are located in the cores of spiral galaxies. There is strong circumstantial evidence for this scenario based upon the apparent continuity and similarity between bright galaxies (such as M87) which observations show do contain massive black holes, radio-quiet active galactic nuclei (such as Seyfert galaxies, which are spiral galaxies), and luminous radio galaxies (which are ellipticals).

Sofia Kirhakos (IAS), Donald Schneider (Pennsylvania State University), and I are analyzing visual-band (F606W) HST images of a sample of 20 of the most luminous nearby quasars (redshifts less than 0.30), all taken with the WFC2 (Wide Field Camera) of the repaired telescope. We have concentrated on nearby quasars in order to obtain the greatest detail and sensitivity regarding the environments of the quasars, especially their host galaxies. We chose, in particular, to study the most luminous quasars in order to investigate whether there are phenomena that occur in these objects that are different from those that occur in more numerous (but less luminous) active galactic nuclei. The observed sample includes both radio-loud and radio-quiet quasars.

Since we want to image faint gas and starlight near the bright quasar nucleus, this investigation would not have been possible without the successful repair mission of the HST. The WFC2 is the preferred instrument since it has a larger field of view and a greater dynamic range than the FOC (Faint Object Camera) and better scattered-light properties than the PC2 (Planetary Camera). Most importantly, the WFC2 can detect lower surface brightnesses than the PC2.

The results have been astonishing in some cases. Instead of the very bright host galaxies that we expected to see in all cases, we have found a number of quasars for which we do not detect convincing evidence of the galactic hosts. If these quasars are indeed located in host galaxies, then they must be relatively faint, in some cases considerably fainter than the typical (Schechter) luminosity of field galaxies. We have also found two bizarre cases in which the quasars appear to have been caught in the act of gobbling up the gas and stars that exist in their immediate vicinity. We have also found a few apparently normal host galaxies containing quasars, although the morphological types of the hosts did not always agree with our expectations. Finally, we have found many cases of distinct galaxies that are projected very close to the quasars, so close that theory indicates that they should fall into the quasar nucleus in the blink of a cosmic eye.

Our results may be summarized as follows. Quasars exist in an extraordinary variety of diffuse environments that range from apparently normal host galaxies, to complex systems of interacting components, to surrounding material that is undetectably faint (so far).

Figure I shows, in the top panel, an 1100 s exposure of the luminous quasar PG 0953+414 (z = 0.239, V = 15.4). This image is to be compared with the lower panel of Figure 1, which shows an 1100 s exposure of a V = 15.8 star imaged with the WFC2. Contrary to expectations, there is no obvious difference between the quasar image and the stellar image. I referred off-handedly to cases like this as "naked quasars" at the Tucson meeting of the AAS, an expression that was enthusiastically adopted by representatives of the press that were present.

Are the quasars really naked (or, more conservatively, "poorly clothed") or have we greatly overestimated our sensitivity to host galaxies? This question is answered by Figure 2, which shows the images of two radio-quiet quasars, PG 0052+251 (z = 0.155, V = 15.4) and PHL 909 (z = 0.171, V = 15.7), whose redshifts and visual magnitudes are similar to those of PG 0953+414.

Figure 2 shows—with exposures similar to that used in preparing Figure l—two apparently normal host galaxies (both about half a magnitude brighter than the typical Schechter field-galaxy luminosity). The image of PG 0052+251 in the top panel shows a beautiful Sb galaxy with bright HII regions. The image of PHL 909 reveals an E4 host galaxy for PHL 909. The host galaxies of PG 0052+251 and PHL 909 are obvious on the unprocessed HST images, demonstrating that we could not have overlooked a similar host galaxy of PG 0953+414.

Figure 2 establishes two other surprising results. First, the association between radio-loud sources and elliptical galaxies is not unique. PHL 909 is radio-quiet, but the host galaxy is an elliptical. Second, the morphologies of the host galaxies of PG 0052+251 and PHL 909 are not significantly affected (at least in the F606W bandpass) by the presence of the tremendous radiation field of the quasar nucleus.

Figure 3 shows the "smoking-gun" evidence for the conclusion that the luminous radio quasar PKS 2349-014 ($z = 0.173$, $V = 15.3$) has been caught in the act of interacting with diffuse gas and stars. The top panel shows the thin wisps that, in other systems of well-studied galaxies, have been shown to be the signature of tidal interactions. There is also a small galaxy just above the quasar image which is projected very close to (1.8", or 3 kpc, from) the quasar nucleus. If, as appears likely, this companion is at the same distance as the quasar, then the luminosity and size of the companion are very similar to the luminosity and size of the Large Magellanic Cloud galaxy. However, the PKS 2349-014-companion is closer to the center of its quasar than our sun is to the center of our Galaxy. Most of our other quasar images also show close companion galaxies.

The lower panel of Figure 3, a compressed image, shows clearly the presence of a large, light-emitting region that envelops PKS 2349-014. Contrary to all theoretical expectations, this diffuse light is not centered on the quasar nucleus. We are unable, with the existing exposures, to say if there is an additional host galaxy that is centered on the quasar center-of-light. Of course, if PG 0953+414 was undergoing a similar interaction with neighboring diffuse material, the components of the interaction would have been obvious on Figure 1.

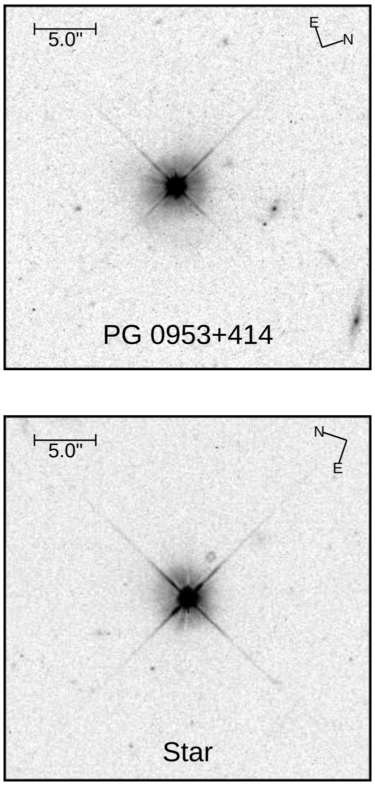

Fig. 1. PG 0953+414 and a field star. The top panel of this figure shows a 1100 s exposure of the luminous quasar made using the HST WFC2 and the F606W filter. Two other exposures, 600 s and 100 s, were also obtained to enable detailed analyses to be performed. The bottom panel shows a calibration exposure of a star with a similar number of observed photons.

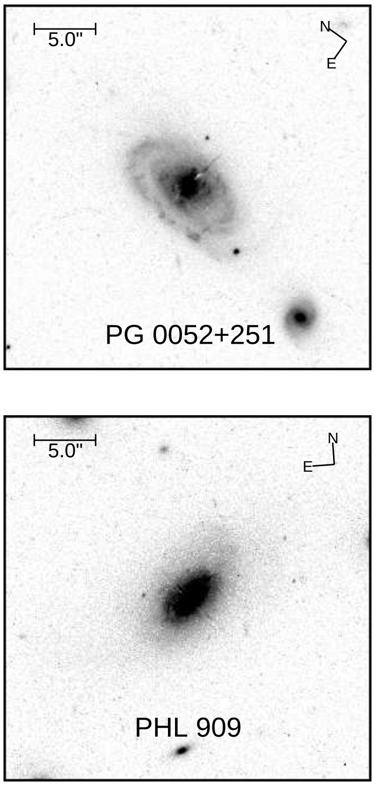

Fig. 2. Host galaxies of PHL 909 and PG 0052+25I. The host galaxies of the luminous quasars PHL 909 and PG 0052+251 are evident in these 1400 s exposures, which like Figure 1, were made using the WFC2 and the F606W filter.

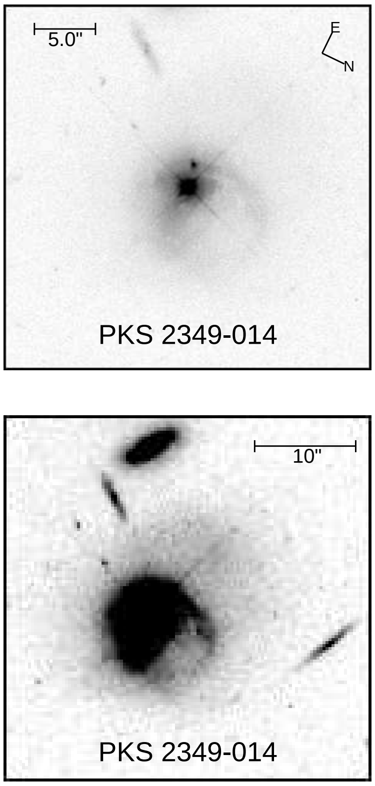

Fig. 3. The “smoking-gun” image of PKS 2349−014. The top panel shows the thin wisps of PKS 2349−014, which approximately surround the quasar, and the presence of a small companion galaxy 1.8″ from the quasar. The lower panel gives a clearer view of the faint, offset nebulosity that envelops PKS 2349−014: this panel was obtained by binning 3 x 3 pixels into a single pixel. Both the upper and the lower panels were made from a 1400 s exposure with the HST WFC2 and a F606W filter.

Most of the pre-launch expectations that we had of what HST would reveal pictures show a richer variety or apparently normal galaxies, of complex systems of interacting material, and of undetected (presumably) faint host galaxies. The new images of nearby quasars, full of surprises as they have proven to be, probably only reveal the tip of the iceberg of quasar environments. Further study should help us to answer some of the fundamental questions regarding quasars for which the HST was designed.

References

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