Part 5
AGN Phenomena

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https://doi.org/10.1017/S0252921100030967 Published online by Cambridge University Press

AGN SURVEYS
ASP Conference Series, Vol. 284, 2002
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Surveys of High-Redshift QSO Hosts

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Abstract.
Recent investigations of high-redshift QSO morphology are reviewed and compared. The PSF-removal is difficult and results are given in several different forms. The reliability of results from HST and ground-based AO are compared, and several caveats to conventional wisdom are given.

1. Introduction

The detection and measurement of QSO host galaxies at redshifts in the range about 1 to 2.5 have been accomplished by a number of investigations in the past decade. I have elsewhere given a review of most of these (see Hutchings 2001 and references therein), and attempted to intercompare the results. My own experience with this kind of work and the very different ways in which the data processing has been undertaken by the various investigations show that a) we are far from having a statistical 'survey' of these objects, and b) we should take a careful look at some of the general claims made about the results.

Similar investigations of radio galaxies - which are claimed to be the same as radio-loud QSOs by many unified scenarios for active galaxies - are also restricted to small samples and diverse observational datasets, as well as significant selection effects by their radio properties. Thus, again, we need to be careful in attempting statistical comparisons of the different groups' samples in 'testing' purely orientation-dependent models.

From my review of the results (Hutchings 2001), I claim that we can believe the following broad properties of higher redshift QSO hosts.

- Host galaxies are resolved in many objects to redshifts 3 and higher. This is because of high resolution data and also the fact that the hosts are very luminous galaxies (see Fig 1).

- While luminous, many host galaxies are compact and blue compared with local universe galaxies. Many are also asymmetric. They appear to have young stellar populations, and are very like the non-AGN Lyman-break galaxies.

- The radio-loud hosts are brighter and have richer companion galaxy environments, and are like radio galaxies with similar radio properties.

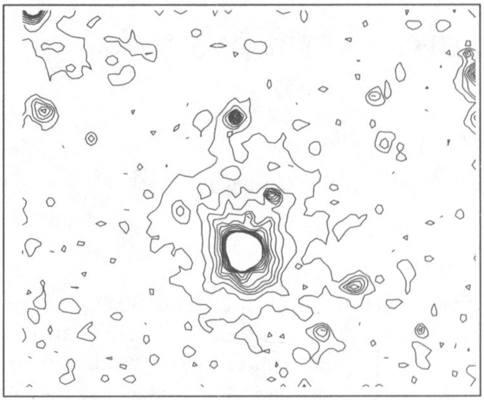

Figure 1. HST CCD (rest wavelength UV) image of z=2 QSO (Hutchings 1998) showing luminous host galaxy

- The QSOs are associated with compact groups of compact galaxies (see Fig 2). Such environments are not found in the local universe.
- Merging and interactions appear to be common in sufficiently deep images.
- Emission-line gas is associated spatially with radio structure. Emission line velocities are large in the few cases investigated.

2. Space Imaging or Ground-Based AO?

The study of high-redshift QSO hosts requires a combination of signal level and spatial resolution, and knowledge of the point spread function. This has led to use of HST and ground-based adaptive optics cameras as the approaches of choice. Since each has strengths and problems, I have attempted to make a comparison of the various critical aspects of the two datasets, as I see them. The table gives this in a cryptic form, and also shows my own scoring system for judging the effects. Overall, I think that we have learned different and complementary things from space and ground-based observing, and neither one is clearly superior. As NGST and large telescope AO systems are put into service, the comparison will need to be remade, but I doubt that a clear 'winner' will emerge.

3. Caveats to Host Galaxy Folklore

The above comparison and my look at the papers of recent years lead me to the following cautionary statements.

- 'Host galaxies are essentially all ellipticals.'

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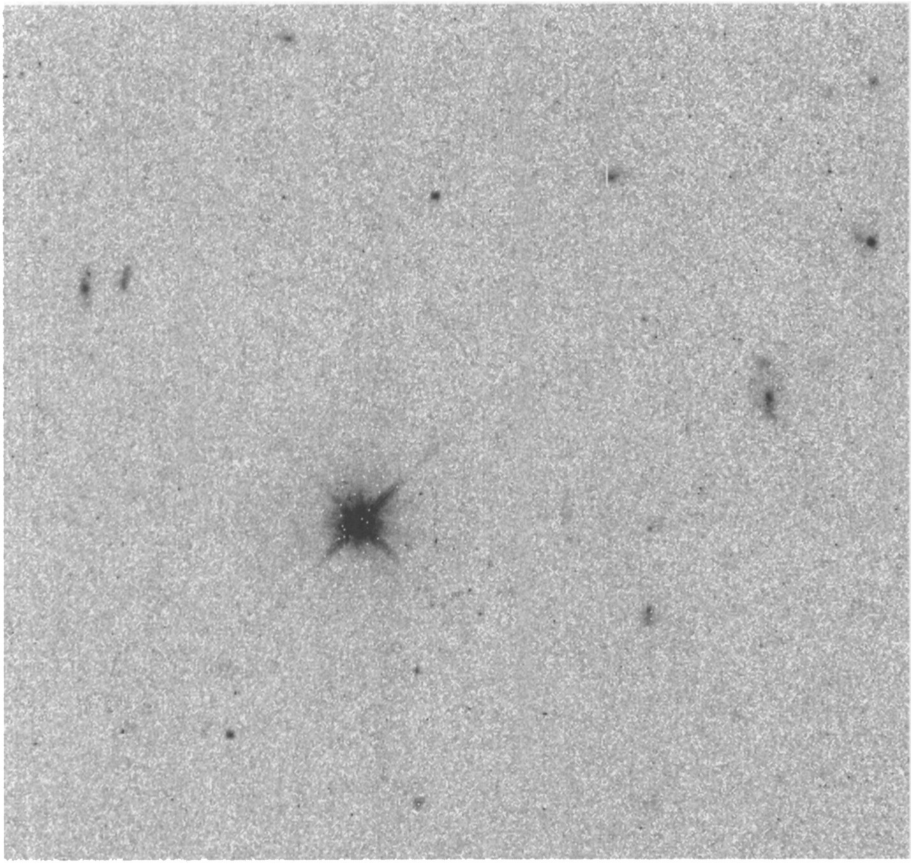

Figure 2. HST CCD image of z=2 QSO 0225-014 with compact companions. Field is 23 arcsec.

Table 1. Comparison of HST and AO data

	HST		Ground-based AO
+	High strehl over whole field	−	Good correction over small field
+	Field size 2-3 arcmin	0	Field size 20 arcsec
−	Undersampled	+	Well sampled
++	Whole sky available	−	Need bright guide star
+	Same strehl at all wavelengths	−−	Strehl increases with wavelength
0	PSF ~const over field and time	−	PSF varies over field and time
−	PSF complex cannot be modelled	0	PSF simple may be modelled
−−	Optical artifacts mask host	−	Low strehl masks host
−−	Small effective area	+	Large effective area
0	Moderate spatial resolution	+	(Much) higher spatial resolution
−−	Noisy, ageing detectors	++	State of the art detectors
++	Dark sky in IR	−	Bright IR sky
−	Scattered light problems	+	Low scattered light
-2	Score	-1	
	Does well		
	Sees 'spheroidal' hosts		Sees tails and disks
	Good colour resolution		Sees faint companions
	Good for low z		Good for high z

HST is good at seeing the bright bulges but not the faint disks and tidal tails. Thus, necessarily shallow HST imaging data will not detect or measure structures beyond the spheroidal population (see Fig 3). We also find (Hutchings et al 2001) from comparing intermediate-redshift galaxy clusters and field galaxies, that galaxies in an interaction-rich environment have brighter bulges and fainter disks as a result.

- 'Radio-loud QSOs have central BH masses of $10^9 M_\odot$.'

  At high redshift, this is based on extrapolating the 'Magorrian relationship'. The growth of central black holes and growth and evolution of bulge populations are unlikely to be related by the same proportionality over the cosmic evolution of galaxies.

  In addition, there are now claims that there is a continuum of radio power - not a dichotomy (e.g. Lacy et al 2001). Thus, the concept of a minimum central mass for radio-emitting jets is not well established.

- 'Many hosts do not look irregular or peculiar: interactions are rare.'

  This statement is usually made from HST data. As noted above, HST 'loses' inner irregular structure because of its complex PSF, and does not reveal faint outer disks or tidal debris by not having enough sensitivity. Deep imaging by larger telescopes do reveal these structures in many QSOs.

- Any claims of a standard ('elliptical' or 'disk') host galaxy type are suspect,

  1. Because of imperfect PSF-removal, leading to incorrect apparent morphology (see Figs 3,4).
  2. Because of azimuthal averaging in models and profiles, which are then forced to fit a pure spheroid or disk model.
  3. Because at high z all galaxies are irregular and not standard Hubble types.

4. Current Survey Questions

In spite of my cautions, we have definitely made some exciting progress, as summarized in Section 1. Thus, we do have an exciting set of possibilities ahead of us in this field, and some important issues to address.

Because of the clear connection now established between central BH mass and the properties of the spheroidal stellar population in the low redshift universe, the study of host galaxies of QSOs (and AGN in general) are of interest in understanding the formation and evolution of galaxies, as well as the mechanisms of the central energy sources. Thus, I list the following questions as important ones for a statistical survey of higher redshift QSO hosts.

1. How and when do central massive black holes form?

2. How and when do QSO host galaxies form?

3. How are the two related a) at galaxy formation, and b) over a galaxy lifetime?

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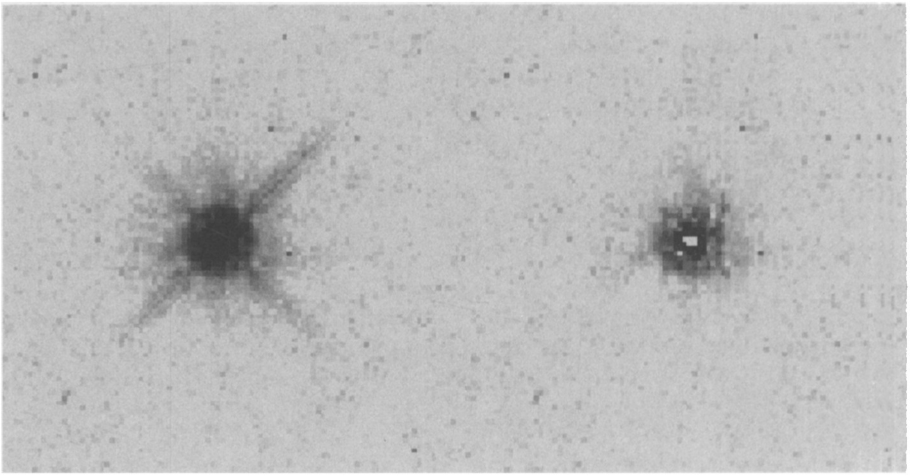

Figure 3. HST image of z=2.3 QSO 0820+296 (left), PSF-subtracted (right). Large telescope images are resolved to beyond the full 4.5 arcsec field shown here.

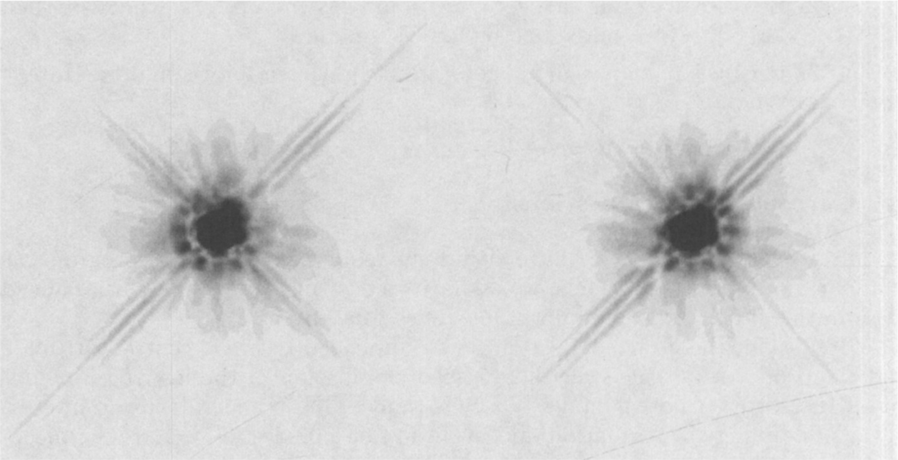

Figure 4. HST PSF models showing sensitivity to optics decentre of 2 mm. Inner PSF structure is about 0.7" across

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4. What is the role of merging in galaxy evolution and BH growth?

5. Is there a radio-loud radio-quiet dichotomy or a continuous range of radio luminosity and structure?

6. Is there a general scenario for central mass flows and spectral absorbers? Does it change with cosmic evolution of galaxies?

I look forward to a real separation of the effects of source-evolution and line of sight orientation with the large and unbiased databases that are being established, and with the new generation of 8m-class telescopes both on the ground and in orbit.

The material for Figures 2, 3, and 4 is from work recently completed with Philip Dumont and Danielle Frenette, and will be published in full elsewhere.

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