On the Shape of the Point Spread Function at the NTT + SUSI

R. FALOMO, Osservatorio Astronomico di Padova, Italy

The actual shape of the Point Spread Function (PSF) is of great importance for several applications. It affects both the spatial resolution and the signal-to-noise ratio of the observations. For a ground-based telescope, the observed PSF shape is in general a combination of instrument and atmospheric effects, with the latter usually dominant during average seeing conditions. Radial brightness profiles of stellar images were already studied more than 20 years ago by King (1971) over a range of several magnitudes using photographic plates. It was found that the PSF has a core (that is commonly described by a Gaussian profile) and a wide wing that produces an extended *halo* around star images (see also Racine, 1996, for further discussion).

A good knowledge of the PSF shape and of its possible variations within the field and with time is crucial when observations at the limit of the instrument capabilities are considered. In this note a quantitative estimate of the difference in instrument performances as a function of PSF changes, based on observations collected at the NTT, is reported.

In the course of a programme aimed at studying faint nebulosities around quasars and BL Lac objects (in collaboration with M.-H. Ulrich) we have obtained several images with the NTT + SUSI (pixel scale 0.13″/pixel) during different sky conditions. The telescope was used in remote control from Garching in January 1996 and the seeing ranged from 0.5 to 1.2 arcsec. In each CCD frame we studied the shape of stars of different magnitude and location in the field. For each object we secured one short (~ 2 minutes integration) and one long (~ 20–30 minutes). No significant trend of star shape was found by comparing short- and long-exposure images, indicating that guiding and tracking were good. From the analysis of the images obtained in sub-arcsec seeing, the shape of the stars was found to be slightly elliptical (ellipticity $\varepsilon \approx 0.05$ to 0.1) with only a marginal dependence on the position in the field.

The radial brightness profiles of the star images were derived from the azimuthal averaging of fluxes, and for each frame a combined profile was produced by merging stars of different magnitudes. We also used saturated stars to extend the profile over several magnitudes after checking that the region of the profile in common with that on non-saturated stars was in good agreement. In spite of small differences of ellipticities of the star images, the azimuthally averaged radial profiles of stars in the same frame are rather similar.

Figure 1a shows a comparison of the PSF profiles obtained during different seeing conditions from various CCD frames. Profiles are normalised to the same peak flux. Seeing values are estimated from the FWHM of the core of non-saturated star images. In Figure 1b the same profiles are reproduced after normalisation to the total flux. This yields a direct idea of how the same point-like object is observed under different seeing conditions. In particular, the large (~ 2 mag) difference in the peak flux from 0.5 to 1.2 arcsec seeing is evident. Also a significant difference is present in the extended wing whose surface brightness changes by ~ 1.5 mag in the same seeing interval (0.5 to 1.2 arcsec). While the variation in the inner part of the PSF influences mainly the spatial resolution and the capability of detecting isolated faint sources, the rise in the wing of the PSF as seeing degrades is a limiting factor when studying features close to bright point-like sources. This is the case for instance in studying host galaxies of quasars and BL Lacs.

The relatively large surface brightness of the PSF halo tends to hide the presence of a real nebulosity (the host galaxy) around the quasar. On the other hand, a poor evaluation of the shape of the PSF may lead one to derive an erroneous contribution of the host galaxy or

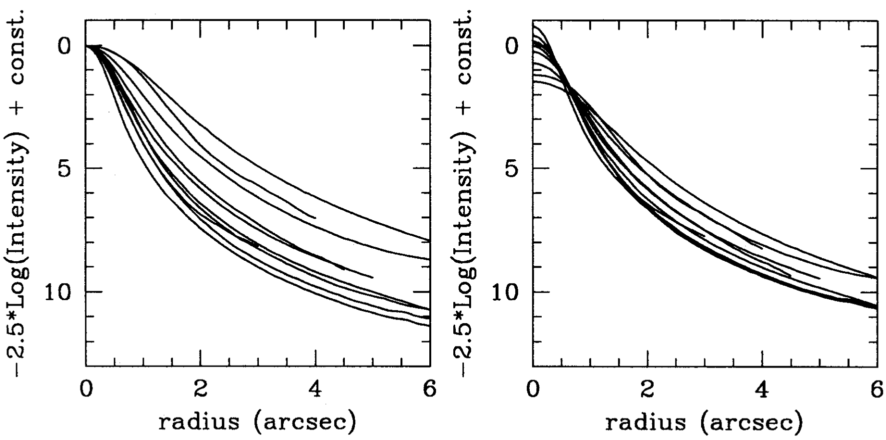

Figure 1: Comparison of radial surface brightness profiles of stars observed with the NTT + SUSI (R filter) under different seeing conditions (FWHM = 0.5 to 1.5 arcsec). The profiles are normalised to the peak flux (a) and to the total flux (b).

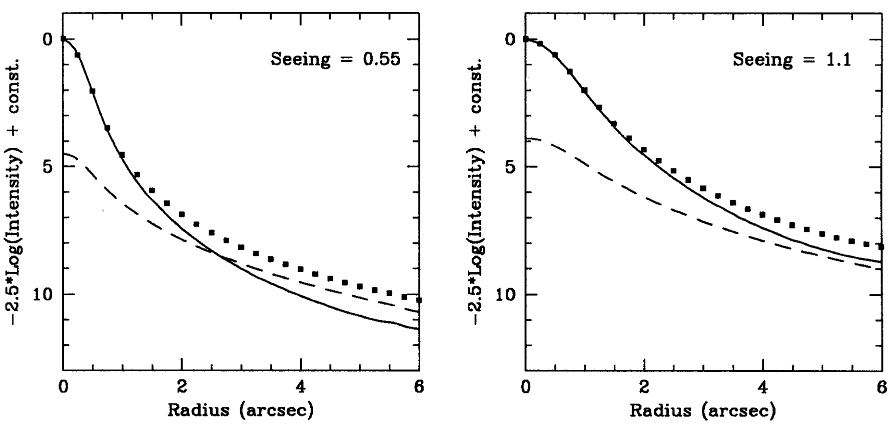

Figure 2: (a): A simulated observation of a quasar (filled squares) through 0.55″ seeing hosted by an elliptical galaxy (dashed line) of effective radius 10 kpc at z = 0.3 and contributing 10% to the flux of the point source (solid line). (b) Same as (a) but for 1.1″seeing.

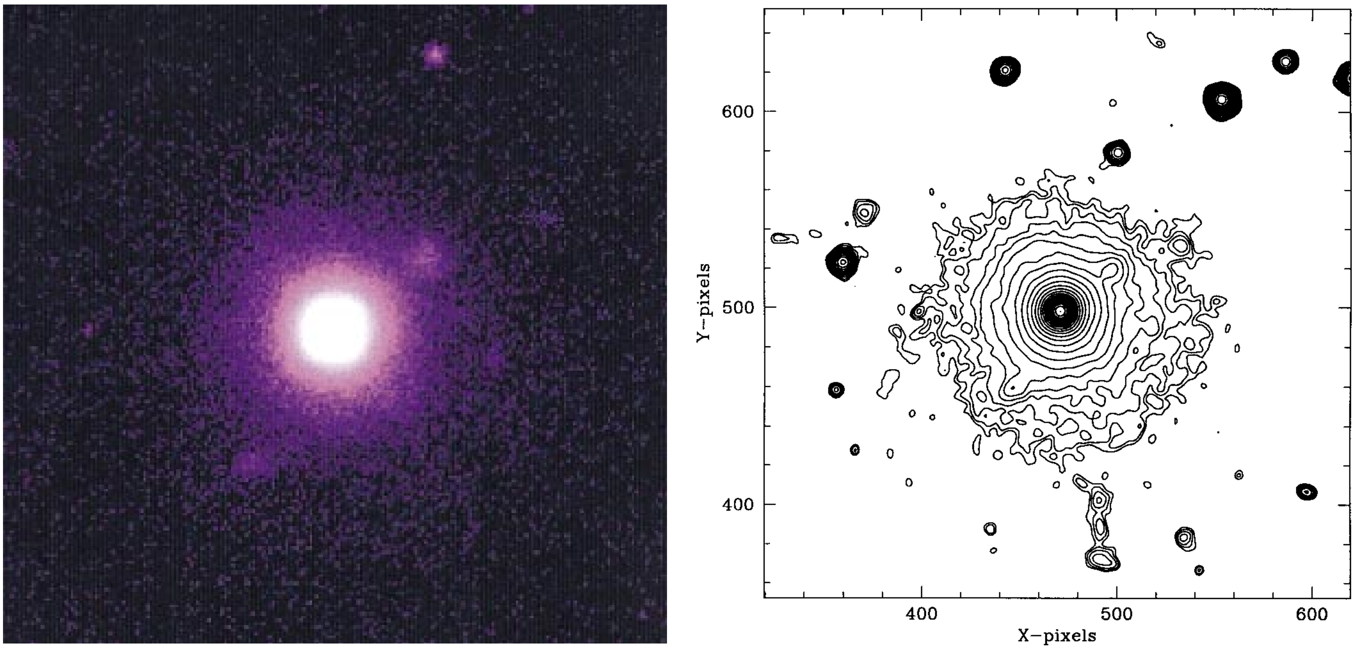

Figure 3: (a): R-band image of the Flat Spectrum Radio Quasar PKS 0736+01 obtained with the NTT + SUSI. The field shown is 25 arcsec on the side with North to the top and East to the left. (b): Contour plot of the field: faintest magnitude is 25.5 per square arcsec and spacing between isophotes is 0.4 mag.

even to find unreal nebulosities if the PSF wing is underestimated. In Figure 2a, b the radial brightness profile of a quasar nucleus is superposed on that of an elliptical host galaxy (effective radius = 10 kpc at redshift = 0.3) of total magnitude 10% of the quasar luminosity after convolution with a PSF corresponding to 0.55 and 1.1 arcsec seeing. The ratio of 10% is roughly the relative ratio found from HST observations for low-redshift quasars observed by Bachall et al. (1997).

With ~ 0.5 arcsec seeing, the emission from the host galaxy begins to be detectable at ~ 1 arcsec and becomes greater than the PSF wing beyond ~ 3 arcsec. If the seeing is 1.1 arcsec, the same object is marginally resolved and the contribution of the galaxy remains below the PSF emission. In the real cases, one has to account for the S/N of the data that should be adequate to study surface brightness emission down to 25–26 mag/square arcsec. This can be obtained with NTT + SUSI in the red with exposures of less than 1 hour during dark time.

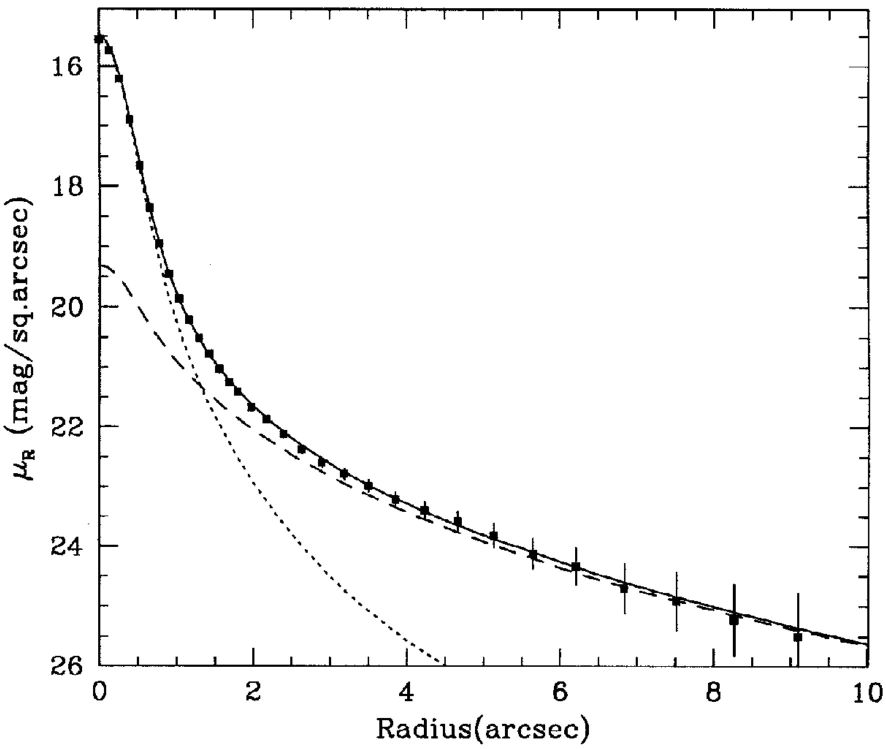

Figure 4: Radial surface brightness profile of the quasar PKS 0736+01 (filled squares) together with the best fit model (solid line). The point source is modelled by a scaled PSF (dotted line) while the host galaxy (dashed line) is given by an $r^{1/4}$ law convolved with the PSF.

In Figure 3 is reported an example of such an observation secured during the 1996 January run with the NTT + SUSI and R filter. The image shows the flat spectrum radio quasar PKS 0736+01 (z = 0.19) as well as two close resolved companions that are embedded in the nebulosity of the object. The radial luminosity profile (see Fig. 4) is very well represented by an elliptical galaxy with a bright point source in the nucleus. It is found that the galaxy has MR = –23.5 and effective radius of ~ 15 kpc (H_0 = 50, q_0 = 0). It is interesting to compare the observed shape of the PSF obtained during sub-arcsec conditions with that of HST. Figure 5 shows the comparison between NTT PSF with 0.55 arcsec seeing and HST + WFPC2 (F814W filter, PC1 detector) PSF as derived from Tiny-Tim (Krist, 1996) model (no scattered light included). The curves are normalised to have the same total flux. While the region within ~ 1 arcsec from the nucleus is clearly better investigated with HST, at larger radii the contributions of the extended wing of the two PSFs are rather similar. The final comparison needs of course to account for different apertures of the telescopes, plate scale and detector performances. This may tend to favour HST data to investigate regions close to the nucleus and ground-based data for the external regions. A combination of the two would yield the optimal characterisation of the host properties.

In both cases, a good modelling of the PSF is a fundamental step for the application of techniques of image analysis as PSF subtraction, deconvolution and co-addition of images with different PSFs. Although there are some limitations (mainly due to the reliability of the models), PSF modelling yields noise-free comparison images that can be easily matched to the observed images. While for HST images a suitable model (e.g. TinyTim) is available (but there are some limitations as the lack of the scattered light contribution); for ground-based data this task is clearly more compelling given the strong seeing dependence of the PSF. From the observed shape of our NTT + SUSI star images it is found that a Moffat function, with $\beta \approx 2.1$ and FWHM that matches the seeing, is a good model down to $\sim$ 10 magnitudes below the peak flux. Beyond this level, there appears to be an excess of the observed PSF with respect to the Moffat model. Although this model could work properly for image deconvolutions and co-additions, when accurate PSF subtraction is involved (as is the case of poorly resolved faint objects) the Moffat model may not be adequate.

References

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King, I, 1971, *PASP*, **83**, 199.
Krist, J. 1996, The TinyTim User's Manual.
Racine, R., 1996, *PASP,* **108**,699.

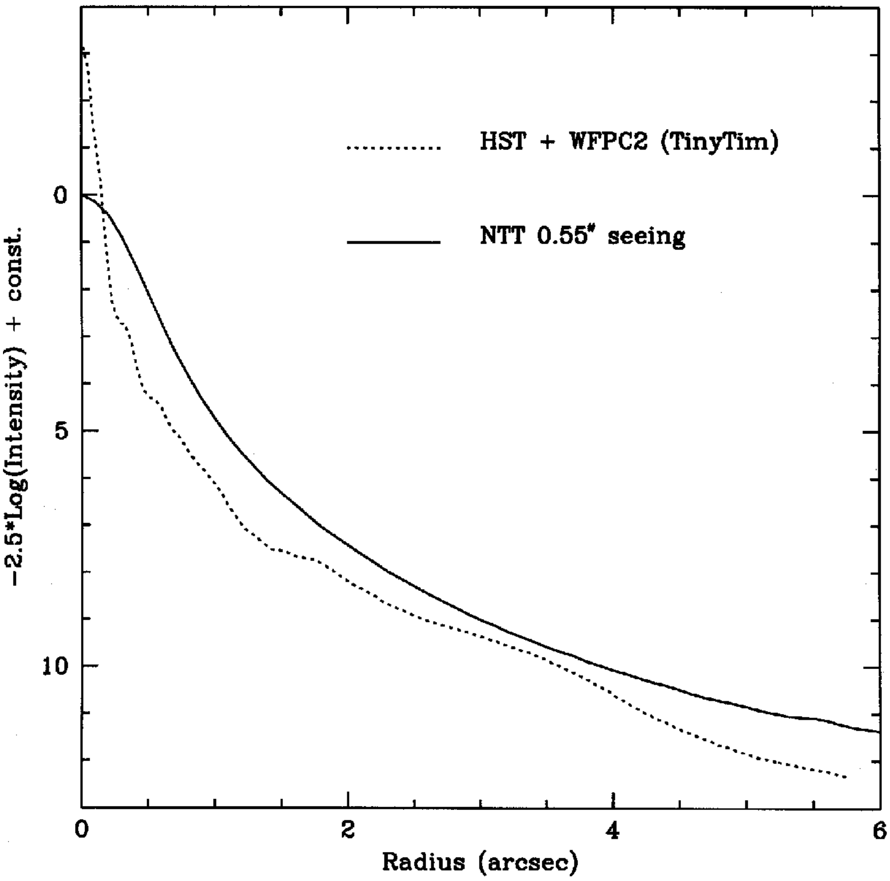

Figure 5: Comparison of NTT + SUSI observed PSF (seeing 0.55″) with HST + WFPC2 TinyTim model of PSF.

Quasar Hosts

A WORKSHOP JOINTLY ORGANISED BY ESO AND IAC

P. Crane and I. Perez-Fournon

The idea that the nuclei of normal galaxies are the hosts of the tremendously luminous sources known as quasars has been around for some time. New instruments and observational techniques have opened a view into the close environment of quasars and allowed us to explore their neighbourhoods and neighbours in unprecedented detail. The ESO/IAC workshop on Quasar Hosts was organised to discuss these developments and their implications. A main objective of the workshop was to explore the nature of the close environments of quasars as well as the relationship between quasars and their somewhat less lofty cousins; Active Galactic Nuclei and BL Lac objects.

This workshop was the first formal scientific contact between ESO and the Instituto de Astrofísica de Canarias (IAC) scientific communities on a topic of mutual scientific interest. The attendees represented most of the researchers active in this field from both communities as well as from outside the ESO and IAC communities.

The workshop venue was the very attractive Conference Centre of the Cabildo Insular de Tenerife in Puerto de la Cruz. Although some people accompanying participants complained about the weather, scientific and technical discussions occupied the full attention of the attendees. The topic, the venue, and the company served well to focus the attention on the objectives of the workshop. The details of the organisation were managed in excellent fashion by the staff at the IAC.

The plenary sessions of the meeting were scheduled over three full days from 24 to 26 September with a round-table discussion and summary on the morning of 27 September. In fact, the final discussion was extremely lively. So much that the local organisers had to shift the venue from the Conference Centre to the bus for the trip to the Observatorio del Teide.

The most exciting development presented at the workshop was the quality and diversity of the new data that are or are becoming available. Of course the results from HST were foremost in many people's minds. They were not disappointed. However, adaptive-optics systems are coming into operation and although the results are sparse so far, the promise is great. This will be especially true in the near-IR where the detector technology has made great advances. Indeed, there were several reports of NIR imaging of quasars, and their hosts were reported even without adaptive optics. To add to everyone's anticipation, several speakers presented results from ISO that were in a preliminary stage of analysis, but were clearly of high quality and promise.

Many attendees were attracted to the meeting by the idea of, or at least hearing tales of, naked quasars. This was not to be, although at least one speaker facetiously thought they might be found locally. These turned out not to be quasars and the images will not appear in the proceedings. It seems that to within the limits of current methods, all quasars are well surrounded by relatively normal