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The Co-Addition Technique Applied to Images of Galaxy Cores

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Abstract. This is a preliminary report on an application of the co-addition technique based upon the Richardson-Lucy algorithm. The combination of high signal-to-noise ground-based images obtained with the ESO NTT using SUSI with high angular resolution HST FOC f/96 images gives new insights on the properties of galaxy cores and their potential time variability.

1. Introduction

Cores of galaxies are one of the main thrusts of present extragalactic research. Answers to questions like the possible presence of massive central dark objects (black holes), central gas/dust disks, nuclear subcomponents and so on are essential to our understanding of the nature and evolution of galactic nuclei and their interrelation with the host galaxy. Many ellipticals and bulges of spiral galaxies show central, unresolved sources which are particularly bright in the UV and significantly less conspicuous or even completely absent in the corresponding visual images. The double nucleus of M31 is such a case: King, Stanford & Crane (1995) found that the brightest peak in the UV is not coincident with the brightest peak in the visual. Attesting to the value of UV observations, we note that *all* the galaxies observed by Crane et al. (1993) which have blue nuclei are also radio sources.

An important discovery was reported by Renzini et al. (1995) The core of the elliptical NGC 4552 contains a *variable* UV source. The galaxy was imaged in the UV using the HST FOC in 1991 and 1993. Over this period the central spike, which is only visible in the UV, brightened by a factor of at least 7. Subsequent observations have revealed broad emission features associated with the flaring region. The UV–bright flare is attributed to tidal stripping of a star during a close encounter with a central black hole. The frequency of such an event is estimated to be of the order of once per 10^4 years in giant ellipticals (Rees 1990). Assuming the complete disruption of the star, the flare is expected to be visible for several years and is predicted to be even brighter than the event observed in NGC 4552. Alternative explanations include the ideas of a collision between two stars, gravitational lensing and the hypothesis of a recent accretion of a gas rich dwarf galaxy whose material settled in the nuclear region. There is some circumstantial evidence to support the latter scenario because extended Hα emission is detected in the central $2''$ region and because there is a nuclear dust lane. However, based upon only one observed case, all the models are unfortunately not well constrained.

2. Observations and Data Analysis

The most complete and homogeneous survey of galaxy cores in the UV has been carried out by Maoz et al. (1995) who obtained a data sample using the pre-COSTAR FOC in the f/96 mode. The analysis of the de-archived images revealed that the majority of the bulge dominated galaxies contain a central UV bright compact source. In those cases where the signal-to-noise ratio was adequate, the central region was further analyzed and the point source nature established. Nuclear subcomponents such as central dust lanes or ring-like structures were identified in some cases.

If the interpretation of Rees (1990) holds true, the brightness variations caused by the flare event in the galaxy nucleus are expected to be observable in a time scale of less then 2 months. A sample of suitable candidate galaxies is now being monitored in the U band using SUSI at the ESO NTT in order to search for UV variability of the central sources similar to that detected in NGC 4552.

The archival FOC f/96 F220W images from the Maoz et al. (1995) survey serve as reference for deconvolving the core regions of the SUSI images using the Richardson-Lucy technique (Hook & Lucy 1994) as also described by Zeilinger (1994). It has been demonstrated that the co-adding technique not only consolidates the signal of images with different resolutions but also conserves the resolution of the sharpest one. One may therefore take full advantage of the high resolution FOC images by co-adding them with (high signal-to-noise) ground-based data.

Nevertheless the ground-based observing programme carried out at the NTT is clearly seeing dependent: In order to derive meaningful core fluxes in combination with the high-resolution FOC images, the seeing conditions should not be much worse then $0.7''$ FWHM and the variation of the seeing for each galaxy data set should not exceed $0.15''$.

The ground-based image is usually aligned with the FOC image in order to leave the image with the weaker signal-to-noise ratio as unprocessed as possible. Because of missing field stars as reference points in the FOC image, the alignment is carried out using the galaxy nucleus itself. An accuracy of typically one FOC pixel ($0.044''$ pixel^{-1}) can be achieved with this method. The selection of an appropriate PSF for the co-addition is a crucial part. For the ground-based images well exposed stellar images are almost always available in the galaxy field to determine the shape of the PSF. In the case of the FOC images one is constrained to know the shape of the PSF in the position of the galaxy nucleus on the detector. Therefore stellar images repeating the exact instrument configuration are almost never available. The software tool Tiny Tim (Krist & Hook 1997) is a solution to this problem. An "artificial" PSF for a given observing date and instrument configuration can be calculated. However, one has to be aware that Tiny Tim is only a tool based upon current best fits of aberration values for the various mirror positions and current best estimates of the obscuration positions and sizes which may still not describe the HST PSF *exactly* (see also Krist 1995).

Typically 100 to 300 iterations of the Richardson-Lucy algorithm are then applied, depending on the signal-to-noise ratios of the input images and the resolution (seeing) of the ground-based image. The latter turns out to be the most serious constraint.

3. Results

We have obtained images of 6 galaxies so far of which one has been observed at two epochs. The images were obtained in service mode under less than ideal conditions. We are proceeding with the analysis.

There are other obvious applications of this technique such as the monitoring variable stars in galaxies.

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