Adaptive optics imaging and TAURUS 2-D spectroscopy of galaxy cores

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Abstract

Many barred galaxies show enhanced star formation activity in ring-like regions around their centres, at typical radii of 1-2 kpc. We show how kinematic (WHT TAURUS Fabry-Pérot velocity mapping) and imaging (CFHT near infrared adaptive optics) observational tests, combined with dynamical modelling, can help in unravelling the dynamics and star formation properties of such circumnuclear regions. Our recent science-driven experience with adaptive optics and with TAURUS is discussed in relation to the future at ING.

Key words: galaxies: structure – galaxies: kinematics and dynamics

1 Introduction

Bars are common, and occur in around two-thirds of all disc galaxies. The gravitational potential of barred galaxies is not axisymmetric, which can lead to inflow of gaseous material from the disc toward the centre of the galaxy. Depending on the existence of resonances, the inflowing gas may pile up around or in the nucleus, which may in turn lead to nuclear or circumnuclear star formation (SF), or nuclear activity (see reviews by Knapen 1999; Shlosman 1999).

Many barred galaxies show enhanced SF activity in ring-like circumnuclear regions (CNRs), at typical radii of 1-2 kpc. The SF may be triggered by spiral armlets or shocks, or result from the gravitational collapse of gas clouds. CNRs are natural 'inflow laboratories': phenomena are not as violent as in AGN; gas and star surface densities are high enough to observe at a variety of wavelengths; and the scales, of a few to 10 or 20 arcsec, are well matched to observational possibilities. In this paper we will concentrate on the use of two observational techniques, adaptive optics (AO) imaging in the near-infrared (NIR), and kinematic observations with TAURUS on the WHT.

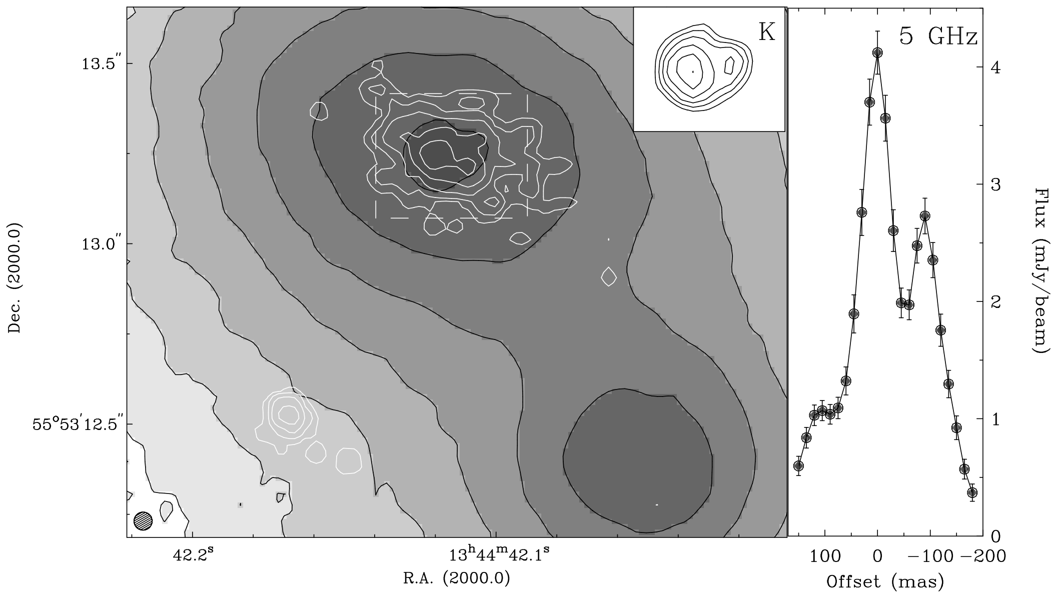

Fig. 1. MERLIN 5 GHz map (contours) of the core region of Mrk 273 overlaid on an AO K-band image obtained with CFHT. From Knapen et al. 1997

2 Adaptive optics imaging

Although with active optics one can now achieve resolutions as good as 0.3 arcsec (e.g. the CNR of M100 imaged with UKIRT: Ryder & Knapen 1999), using AO on 4-m telescopes one can beat even the HST in terms of spatial resolution in the K-band. We have used the Canada-France-Hawaii Telescope (CFHT) AO system PUEO on several occasions in the NIR. This system has over the last few years proven that AO works in practice, and can deliver diffraction-limited images. As an example, we show in Fig. 1 our K-band image of the core region of the ultraluminous infrared galaxy Mrk 273 (greyscale and inset), along with MERLIN radio continuum data (contours and profile on right). At a spatial resolution of around 0.12 arcsec, the NIR image shows a double nucleus within the main core component, which is confirmed with the same separation (of $\sim 90\,$mas) in the MERLIN data (Knapen et al. 1997). We also imaged a number of CNRs in barred galaxies, finding intricate dust lane structure and evidence for massive SF from the NIR imaging (see e.g. Laine et al. 1999, who find a grand-design mini spiral inside the CNR in NGC 5248).

However, diffraction-limited imaging, such as shown in Fig. 1, depends on full correction, which can only be achieved on a point source of sufficient brightness, either a nearby star, or the object itself. Only a small portion of the sky is covered by the areas around stars that are sufficiently bright to be used as AO guidestars. AO imaging of extended objects must thus usually be done using a central peak in that object, and where such a peak is not available, or where it is not bright or peaked enough, AO imaging will give either disappointing results, or none at all. Since the shape of the PSF after AO correction depends on the shape and strength of the reference source, studying samples of extended objects, even if they are centrally peaked, is very difficult with AO. The way forward is of course by using laser guide stars, as discussed elsewhere in this volume (see contribution by Longmore), which will make almost the complete sky accessible for reliable and good AO imaging.

3 TAURUS kinematic observations

Observations of the kinematics of CNRs is fundamental to test numerical modelling and the underlying theory. Such observations must give two-dimensional information, which in practice excludes long-slit spectrocopy. Integral field units are powerful instruments due to the high spatial and spectral resolution and the inherent possibility of performing multi-line measurements (giving stellar and gas kinematics). However, the field of view remains limited if high spatial resolution is required, even in modern instruments like SAURON (see Peletier, this volume). Fabry-Pérot spectroscopic imaging in e.g. the Hα line gives fully sampled high-resolution ($< 1''$) 2-D kinematics across a field of view of up to $5'$ across. Traditionally, there is a perception of a two-fold difficulty in using such data: data reduction and interpretation. But, about a decade after TAURUS became operational, these problems have largely been surmounted. For example, on a fast workstation with ample disc space and internal memory, we now routinely reduce a data set of, e.g., 700×700 pixels $\times 55$ velocity planes within an hour. Interpretation is done using techniques which have long been routine in aperture synthesis radio astronomy.

For the CNR of M100 (=NGC 4321), the Hα velocity field at ~ 0.6 arcsec resolution shows evidence for a steeply rising rotation curve, reaching the large-scale disc value within 200 pc from the nucleus, as well as for streaming motions in the ionized gas due to miniature density wave spiral arms, and to gas motions along the inner part of the bar (Knapen et al. 1999). These findings confirm our previous results from observations of the morphology, and from detailed numerical modelling (Knapen et al. 1995).

4 Concluding remarks

AO works in practice, and is used to obtain high-resolution images and scientific advances in a range of fields in astronomy. At full correction, diffraction-limited imaging can be obtained, with spatial resolution as high as 0.1 arcsec. Of prime importance in reaching such high resolutions, however, is the use of suitable guide stars, or in the absence of those, the science target itself. In order to allow imaging of (nearly) the complete sky with reliable resolution and PSF shape, the use of laser guide stars is imperative.

As for TAURUS, it seems that finally, about a decade after its commissioning, the Fabry-Pérot mode can be used to its full potential. Due to its re-imaging optics and filter set, TAURUS is also arguably the best narrow-band camera at the ING, capable of delivering excellent images (e.g. Rozas, Beckman & Knapen 1996; Knapen 1998).

New developments are exciting and bode well for the future. The blue and red TAURUS Tunable Filters (TTFs) provide the opportunity to select a filter response with random central wavelength and “filter width”, thus allowing for a host of exciting programmes in a wide range of areas, including cosmology (see e.g. the TTF homepage[1]). The ING TAURUS needs an upgrade, but we argue that such an upgrade should be made. Incorporating features pioneered at the AAT such as charge shuffling on the CCD or perhaps LDSS-like capabilities, in combination with access to the Northern sky, and under significantly better seeing conditions than those prevailing at the AAT, will make TAURUS a niche instrument that will not be easily sidelined by instrumentation on other 4- or 8-m telescopes.

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