SAURON: Integral-field Spectroscopy of Galaxies

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Abstract

We present the first results from a new and unique integral-field spectrograph, SAURON, for the 4.2-m William Herschel Telescope on La Palma. Based upon the TIGER concept, SAURON uses a lens array to obtain two-dimensional spectroscopy with complete spatial coverage over a field of $33'' \times 41''$ in low-resolution mode ($0.94''$ lenslets) and of $9'' \times 11''$ in high-resolution mode ($0.26''$ lenslets). The spectra cover 4800Å to 5400Å with a resolution of 3Å ($\sigma = 75$ km s^{-1}). SAURON achieved first light during commissioning on the WHT on 1 February 1999. The instrument performed well and we are commencing a systematic survey of the velocity dispersions, velocity fields, and line-strength distributions in nearby ellipticals and spiral bulges. The wide field of SAURON will be crucial for unraveling complicated velocity structures. In combination with available long-slit spectroscopy of the outer regions of the galaxies, HST spectra of the nuclei, and HST imaging, we will constrain the intrinsic shapes, mass-to-light ratios, and stellar populations in spheroids. In this presentation we will give a status report and preliminary results from our first science run in February 1999.

Key words: Integral Field Spectroscopy – Elliptical Galaxies – Spiral Galaxies – Stellar Kinematics – Stellar Dynamics – Stellar Populations

1 Introduction

Understanding the formation and evolution of elliptical galaxies and spiral bulges is complicated by the observation that many, if not all, of these systems are triaxial or have multiple kinematic components. Triaxiality leads to complicated velocity structures that are difficult to map using long-slit spectroscopy. In addition, the central few arcsec are often *kinematically decoupled*: the inner and outer regions appear to rotate around different axes (Illingworth & Franx 1989). This makes *two-dimensional* (integral-field) spectroscopy of stars and gas essential for determining the dynamical structure of these systems. Therefore, in a collaborative effort, groups in Lyon, Leiden, and Durham decided to build `SAURON`, a unique IFU with a large field of view and high throughput that is optimized for studies of the kinematics of gas and stars in galaxies.

2 The `SAURON` Instrument

`SAURON` (Spectroscopic Areal Unit for Research on Optical Nebulae) is a `TIGER`-like integral field spectrograph (Bacon et al. 1995) with an array of 1520 square lenses, built for the William Herschel Telescope of the Isaac Newton Group on La Palma. The focal plane is sampled by an array of square lenses whose projected sizes on the sky can be set via the appropriate enlarger to $0\farcs94$ or $0\farcs26$, corresponding to fields of view of $33'' \times 41''$ or $9'' \times 11''$, respectively. About 70 dedicated lenses sample an area offset $1.7'$ from the main field, to allow accurate sky subtraction. Unlike fiber *dense packs*, the spatial coverage is 100%. `SAURON` complements `OASIS` on the CFHT, which allows high spatial resolution sampling of the central regions (e.g., one can obtain a $4\farcs1 \times 3\farcs3$ field with $0.11''$ sampling for use with the Adaptive Optics Bonnette).

The grism is optimized for the spectral domain 4800–5400 Å, which includes important absorption/emission lines such as the Mg triplet, the Fe lines, Hβ, [OIII]4959,5007, and [NI]5199. The instrumental velocity dispersions are 82 km s^{-1} ($0\farcs94$ sampling) or $\sim$64 km s^{-1} ($0\farcs26$ sampling).

3 Commissioning and Some Preliminary Results

`SAURON` was commissioned on the WHT 1–5 February 1999 and the first science run was 14–21 February. The instrument performed admirably. We focused the optics, aligned the CCD/grism/lenslet array, and adjusted the baffling to remove stray light and reflections. To prevent the spectra from overlapping,

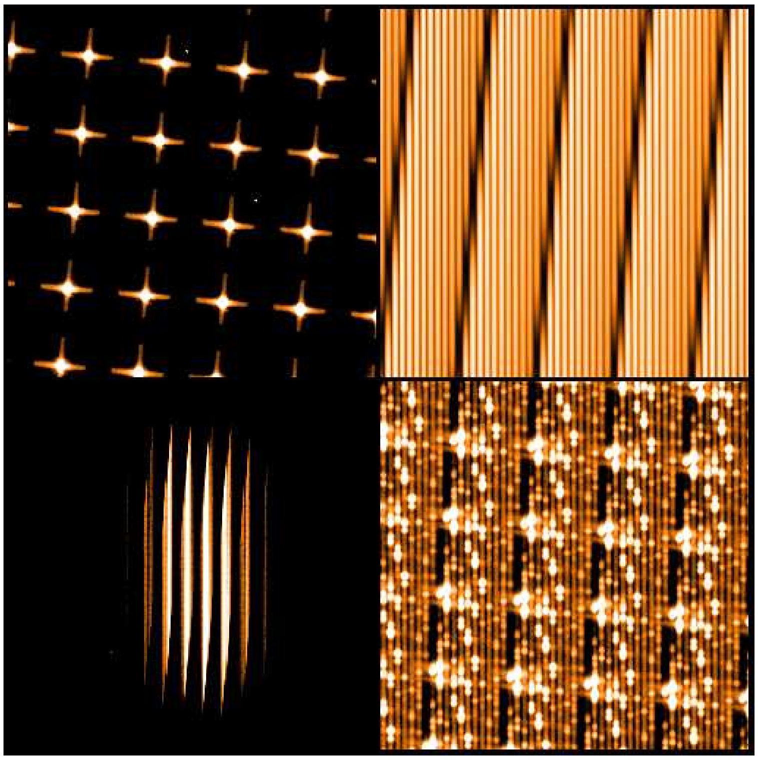

Fig. 1. Various SAURON calibration frames. From upper left turning clockwise: a) Micro-pupil image taken with the grism out. b) Continuum image taken with a tungsten lamp. c) Neon arc. d) Template star HD 85990. Note that the scale in figure 1d is different from the other panels.

the angle between the grism and the lenslet array was set to 5$^\circ\!\!.$19. Flexure was found to be less than 1 pixel in both the spatial and the spectral directions in $\sim$1800 seconds.

Figure 1 shows an example of various types of SAURON calibration frames. Each panel shows only a small part of the full 4000 $\times$ 2000 EEV12 CCD image so that details can be seen. Two low-resolution spectra from the centers of the elliptical galaxies NGC 3377 and NGC 4278 showing the features of interest are shown in Fig. 2. The absorption lines will be used to study stellar populations in two dimensions in the galaxies, as well as the stellar kinematics, by analysing their line profiles, which, amongst others, will give maps of radial velocity, velocity dispersion, and line asymmetry. The emission lines give information about motions in and the physical condition of the ionised gas.

We are currently in the process of adapting the OASIS data reduction software to be used for SAURON. The close packing of the SAURON spectra increases the necessary precision of the extraction process. To account for contamination from neighboring spectra we will employ an optimized method that models the distortion of the optics and fits a PSF at each wavelength of each spectrum. We are also developing a data reduction pipeline and a data archive.

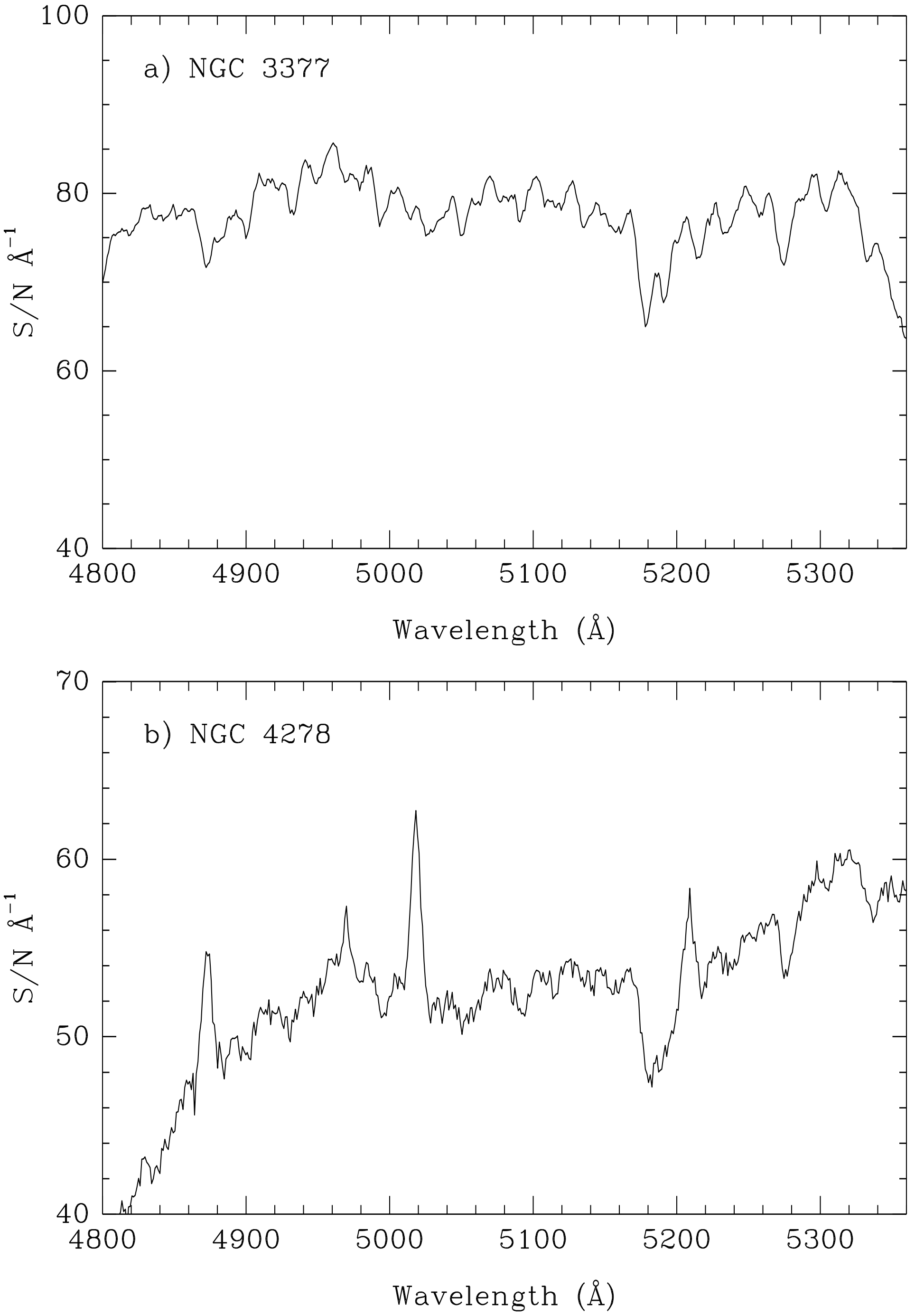

Fig. 2. Signal-to-noise per pixel of about 75 is obtainable in galaxy cores in 1800s with SAURON's LR mode. Upper panel: NGC 3377, a rotating elliptical. Lower panel: NGC 4278, an elliptical with relatively strong emission lines.

Figure 3 shows results of a very preliminary reduction of the data of NGC 3377. The reconstructed image agrees well with surface photometry in the literature, and one can clearly see the rotation of the galaxy along the major axis, in agreement with longslit spectroscopy. The Mg*b* line strength is enhanced in

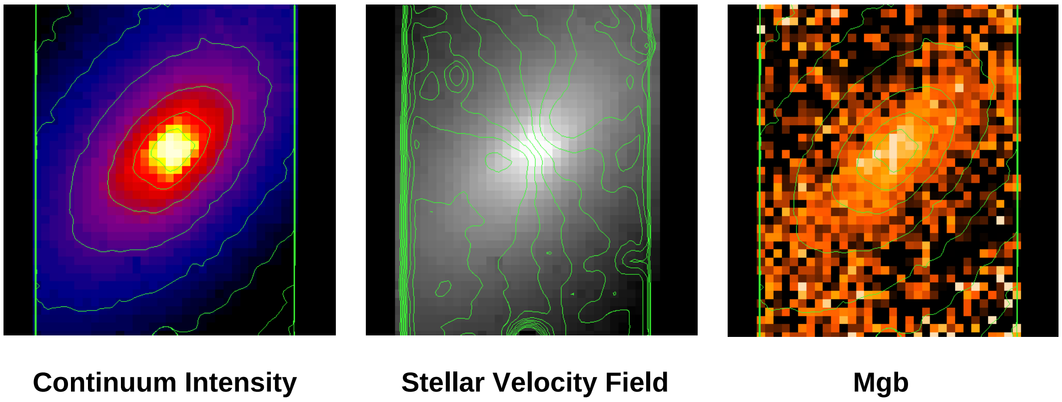

Fig. 3. Some preliminary SAURON results for NGC 3377. left: Reconstructed continuum image. Middle: Radial velocity contours on top of the continuum. Right: Mgb absorption line strength map. Field size is $30\overset{''}{.}0 \times 38\overset{''}{.}5$.

the center, and it appears that the isochromes (lines of constant metallicity/colour) are flatter than the isophotes, which would indicate the presence of a flattened central disk.

We will compare the data with fully general numerical galaxy models built with Schwarzschild's numerical orbit superposition method. The models make no assumptions about velocity anisotropy and account for PSF convolution and the finite size of the spatial element (i.e., microlens). The method was applied successfully to determine BH masses in the E3 galaxy M32 (van der Marel et al. 1998) and in NGC 4342, an E7/S0 in Virgo (Cretton & van den Bosch 1999).

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