Stellar Populations of Kinematically Decoupled Cores in E/S0 Galaxies

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1. SAURON and OASIS Projects

The SAURON Project (de Zeeuw et al. 2002, MNRAS, 329, 513) surveyed 72 nearby E/S0/Sa galaxies using the SAURON integral-field spectrograph (IFS) on the William Herschel Telescope (WHT). We are conducting a follow-up survey of the 48 E/S0s at higher spatial resolution. The first 28 galaxies were obtained with OASIS IFS at the Canada-France-Hawaii Telescope (CFHT, now at WHT), and are presented in McDermid et al. (2006, MNRAS, *submitted*). This survey is ongoing at the WHT, with additional observations using GMOS on Gemini. (Fig.1)

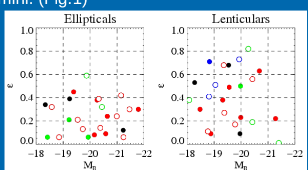

Figure 1. SAURON sample of 48 E/S0 galaxies. Filled symbols indicate objects from a 'cluster' environment; open symbols indicate 'field' objects. Coloured symbols indicate the objects observed with OASIS at the CFHT (red), and so far observed with OASIS at the WHT (green) and GMOS (blue).

2. Two kinds of early-type galaxy

The stellar velocity fields of the SAURON E/S0s (Emsellem et al. 2004, MNRAS, 352, 721) fall into two broad categories: those showing clear rotation about a single axis, generally aligned with the photometry; and those which show little net rotation, except for a possible sub-component that is usually misaligned with the photometric axis. We term these fast-rotators and slow-rotators respectively. The classification of these two types is described quantitatively in Emsellem et al (2006, MNRAS, *submitted*, Paper IX).

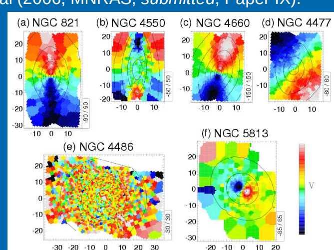

Figure 2. Examples of stellar velocity fields illustrating fast-rotating galaxies (top four panels) and slow-rotating galaxies (bottom two panels).

3. Need for Spatial Resolution

SAURON is a wide-field IFS with relatively coarse spatial sampling (0.94" spaxels). Our OASIS data have a smaller field of view (approx. 8" square), but sample the sky with 0.27" spaxels, resulting in an average factor 2 better PSF than SAURON. This is crucial to study galaxy centers, where PSF effects are significant. Fig.3 illustrates this, showing that OASIS provides much sharper measurements of central structures, revealing components barely seen with SAURON.

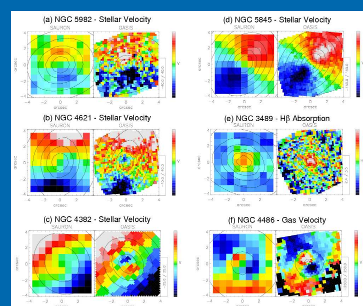

Figure 3. Comparison of SAURON (left) and OASIS (right) observations of E/S0 galaxy centers from the SAURON project. The field sizes are the same between the pairs of panels, as are the intensity scales. Isophotes from the integrated spectra are overlaid. The maximum and minimum levels are given in the inserted tab, where units are km/s for velocity fields and Å for line-strength indices.

4. The SAURON View: Old, large KDCs

Several galaxies in the SAURON sample show stellar subcomponents that rotate in a different direction and/or with a different rotation axis to the rest of the galaxy. We term these 'kinematically decoupled cores' (KDCs). From SAURON stellar absorption line strengths (Kuntschner et al. 2006, MNRAS, 369, 497, Paper VI), these KDCs appear generally coeval with their host galaxies, with no significant age difference between the central and outer parts (Fig. 4). This suggests the stars in these components formed at early epochs.

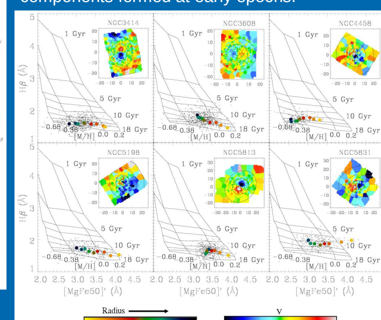

Figure 4. SAURON observations of 6 KDC galaxies. Stellar velocity fields are shown as inserts. Line-strength indices are overplotted on stellar population models to show variations in age and metallicity. Small black points show measurements from each SAURON bin; large coloured symbols show averages along isophotes. Lighter symbols indicate the central regions.

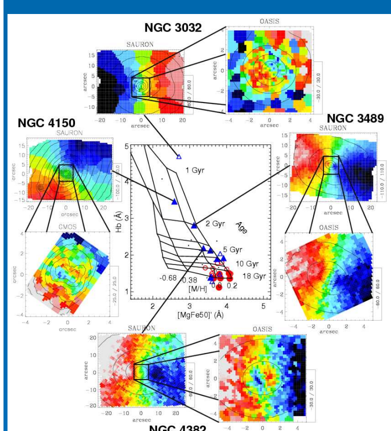

Figure 5. Central insert shows integrated line-strength values within Re/8 from SAURON (Paper VI). External inserts show the stellar velocity fields as observed by SAURON (first panel), and the central stellar velocity field observed at high spatial resolution (zoom in).

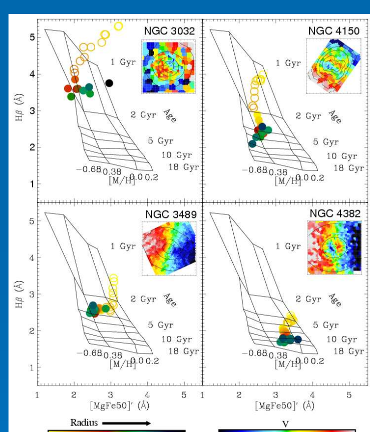

Figure 6. Stellar populations of the four galaxies in Fig. 5. Inserts show the stellar velocity fields. Filled symbols are radially-averaged line-strength values from SAURON. Open symbols are those from OASIS. Symbol colours indicate circular radius, with lighter symbols corresponding to the central regions.

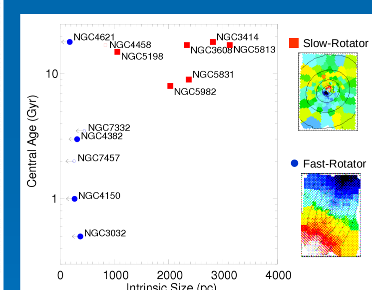

Figure 7. Intrinsic diameter of the KDCs in our sample (estimated from the SAURON and OASIS velocity fields), against the luminosity-weighted age measured within the central 1". Arrows indicate upper limits in size. Symbols correspond to fast- and slow-rotating galaxies, as defined in Paper IX. The insert velocity fields show the qualitative difference between fast and slow rotator galaxies.

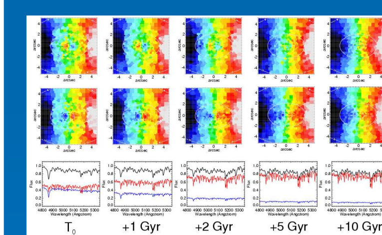

Figure 8. Simple model assigning young stars to the kinematic subcomponent, such that the total spectrum is comparable to NGC4150. The two populations are evolved forward in step, with the result that the subcomponent becomes less visible. A counter-rotating component (top) is easier to detect than a co-rotating one (bottom). After 5 Gyr, the subcomponent is barely detectable.

5. The OASIS View: Small, Young KDCs

Of the 4 galaxies with the youngest luminosity-weighted ages in the OASIS sample, 3 show counter-rotation in their central stellar kinematics when viewed at higher spatial resolution, with the other showing a possible mild twist (Fig. 5). The stellar populations within these sub-components are distinctly young compared to the outer parts (Fig. 6), suggesting a link between the kinematic substructure and recent star-formation, such as stars forming from material accreted with opposite angular momentum.

6. KDC sizes and ages

Considering all cases of KDCs in the SAURON sample, we find two kinds of KDC: kiloparsec-scale KDCs, which are older than 8 Gyr, and are found in galaxies with little net rotation; and compact KDCs, which have intrinsic diameters of less than a few hundred parsecs, show a range of stellar ages (0.5-15 Gyr, with 5/6 younger than 5 Gyr), are found exclusively in fast-rotating galaxies, and are close to counter-rotating around the same axis as their host. (Fig. 7)

7. Discussion

The compact, young KDCs, revealed in fast rotators by OASIS are fundamentally different from the kpc-scale older KDC's found in slow rotators. Their young stars and the nature of their hosts strongly indicate that dissipation has been key to their formation, although the amount of gas required is negligible compared to the total baryon mass within about 1 kpc (in contrast to the big KDCs). The apparent lack of old or co-rotating compact KDCs in fast rotators may be due to a luminosity evolution, as illustrated in Fig. 8, which shows the more subtle signature of a co-rotating system, and that the counter-rotating subcomponent is barely visible after about 5 Gyrs.

8. Conclusions

- OASIS IFS observations of SAURON galaxies show previously unresolved features
- OASIS data reveal a population of KDCs composed of distinctly young stars
- Large (few kpc) KDCs are old and found in slow-rotating galaxies
- Compact (few 100 pc), young counter-rotating cores only found in fast-rotating galaxies
- Dissipational processes were involved in forming the young, small KDCs
- Small KDCs have little mass, and can fade into the background galaxy within 5Gyr
- Larger sample required to understand counter-rotation and star-formation links