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KINEMETRY: QUANTIFYING KINEMATIC MAPS

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Abstract

We describe a new technique, *kinemetry*, to quantify kinematic maps of early-type galaxies in an efficient way. We present the first applications to velocity fields obtained with the integral-field spectrograph SAURON.

Integral-field spectrographs (IFS) were designed to provide spectra over the full spatial extent of the observed objects. Applied to early-type galaxies, they can produce complete maps of the stellar kinematics. To date, these maps have been used 'as is', without fully exploiting all the information they contain (e.g., Davies *et al.* 2001). Still, it is known from the study of the surface brightness distribution of early-type galaxies that proper quantification, e.g., via the a_4 distortion parameter, can shed new light on these objects (Kormendy & Djorgovski 1989). For this reason we have developed *kinemetry*, a new formalism which extends the photometric approach to kinematic maps obtained by IFS.

1 Photometry & kinemetry

The core of the dynamics of an early-type galaxy is embodied by its stellar distribution function (DF) $f(\mathbf{r} \equiv (x, y, z), \mathbf{v} \equiv (v_x, v_y, v_{[z]}))$. This fundamental quantity cannot be measured directly, but different observations constrain it.

The surface brightness at any point in a galaxy image equals the DF integrated along the line-of-sight (LOS): $\mu(x, y) = \int_{\mathrm{LOS}} \mathrm{d}z \iiint \mathrm{d}\mathbf{v} f(\mathbf{r}, \mathbf{v})$. The study of this projected light distribution is often referred to as the *surface photometry*.

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Spectroscopic observations of a galaxy provide the line-of-sight velocity distribution (LOSVD): $\mathcal{L}(v;x,y) = \int_{\rm LOS} {\rm d}z \iint {\rm d}v_x\, {\rm d}v_y\, f(\mathbf{r},\mathbf{v})$. This is the ultimate kinematic observation for early-type galaxies. The surface brightness is just the zeroth-order moment of the LOSVD. Its low-order moments V, σ, and related quantities h_3 and h_4, are in regular use as probes of the galactic DF (e.g., van der Marel & Franx 1993).

In what follows, we extend the techniques of surface photometry to the stellar kinematic maps, i.e., to the higher projected moments of the DF. This approach, which we christen *kinemetry*, has never been developed fully, mostly because the required maps were difficult to obtain until the recent advent of panoramic IFS.

2 Kinemetric expansion

Few papers have addressed the problem of parametrization of the stellar kinematics of early-type galaxies (e.g., Franx *et al.* 1991, Statler 1994), and none have considered the case of IFS data. Following techniques developed for HI maps (e.g., Schoenmakers *et al.* 1997), we use a simple Fourier expansion of the projected kinematic quantity $K(x, y)$ expressed in polar coordinates on the plane of the sky:

$$K(r,\theta) = a_0(r) + \sum_{i=1}^{N} c_i(r)\, \cos[i(\theta - \phi_i(r))].$$

This harmonic expansion is the most straightforward and powerful choice, and nicely follows the usual surface photometry approach (e.g., Franx *et al.* 1989).

Here we consider only the mean velocity fields. Similar expansions can be applied to higher moments, once the moment parity is properly taken into account. A full description of the method will be published elsewhere.

3 Applications

We now present some preliminary results of the kinemetry technique, as applied to the SAURON observations of elliptical galaxies (Bacon et al. 2001, de Zeeuw *et al.* 2001, Copin *et al.* this volume).

Kinemetric parameters. Fig. 1 shows the dependence of the amplitudes c_i and phases ϕ_i on radius in the galaxies NGC 4365 (E3) and NGC 1023 (SB0). The coefficient c_1 is always *dominant*, and is related to the amplitude of the velocity curve. We therefore express the $c_{i>1}$ as fractions of c_1. The phase ϕ_1 is the *kinematic angle*, and gives the main orientation of the velocity field at a given radius. Its radial dependence clearly displays the extent and orientation of kinematically decoupled cores (e.g., NGC 4365) and kinematical twists, a likely signature of triaxiality (e.g., NGC 1023). The amplitude c_3 can be considered as the *morphology parameter*, as it encompasses most of the 'geometry' of the velocity field: third-order reconstructed fields already display most of the interesting features.

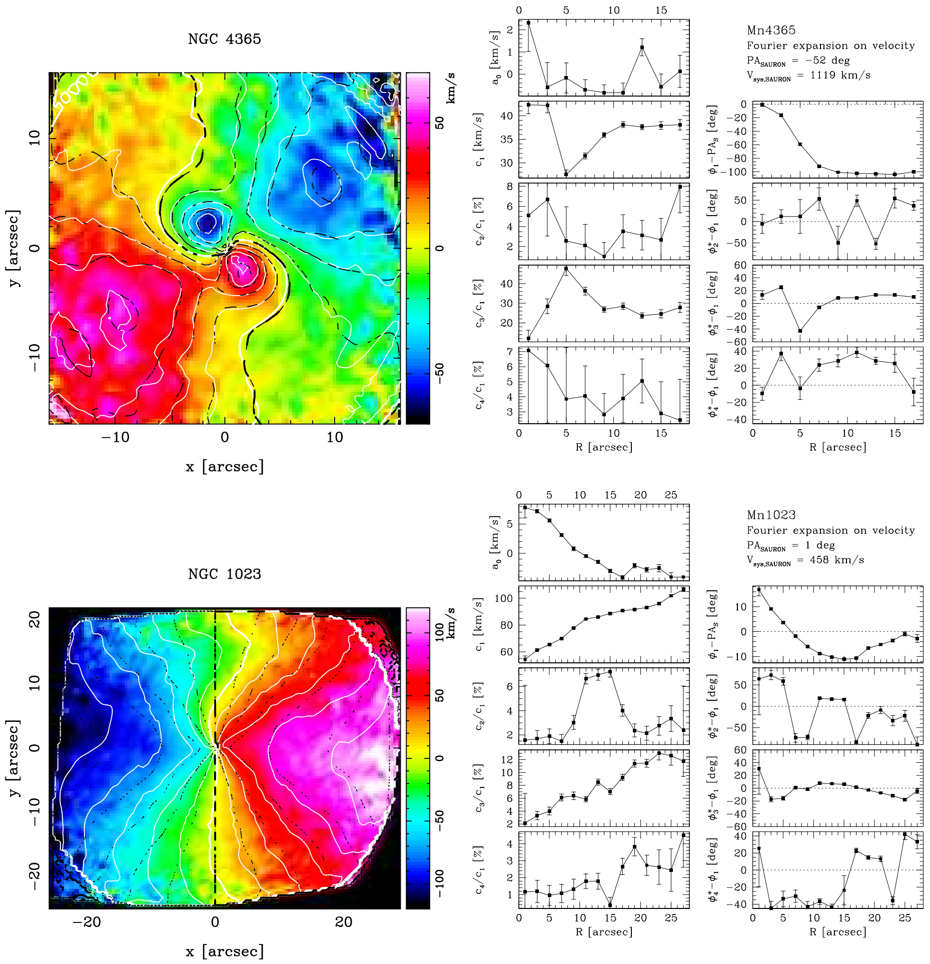

Fig. 1. Kinemetric analysis of NGC 4365 (*upper panel*) and NGC 1023 (*lower panel*). *On the left:* observed velocity field (*grayscale*), fourth-order reconstruction (*white contours*) and 'triaxial' (for NGC 4365) or 'axisymmetric' (for NGC 1023) approximations (*black contours*). *On the right:* kinemetric parameters – amplitudes (*left panel*) and phases (*right panels*) up to fourth order – as function of radius.

Filtering. Since velocity maps are mostly point-antisymmetric ($V(r, \theta + \pi) \simeq -V(r, \theta)$), the even moments will generally be smaller than the odd ones. Going further, one can use kinemetry as a powerful filtering tool to obtain the 'closest' velocity field compatible with a given intrinsic symmetry: a triaxial (bi-symmetric) galaxy has $V(-x, -y) = -V(x, y)$, giving $a_0 \equiv 0, c_{2n} \equiv 0$; and an axisymmetric galaxy ($V(x, -y) = V(x, y)$) requires furthermore that $\phi_{2n+1} \equiv \mathrm{PA}$ (see Fig. 1).

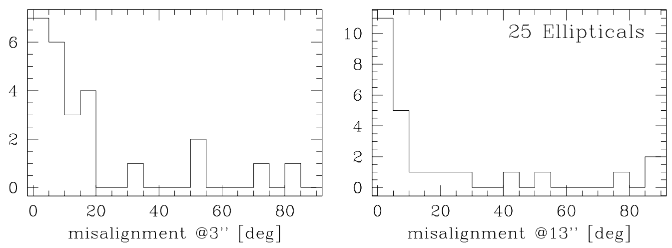

Fig. 2. Kinematic misalignment histogram for the 25 elliptical galaxies of the SAURON sample, measured at 3 arcsec (*left panel*) and 13 arcsec (*right panel*).

Kinematic misalignment. The kinematic misalignment angle Ψ, defined as the difference between the position angle of the major axis and the kinematic angle, is of particular interest in the study of the intrinsic structure of early-type galaxies (e.g., Binney 1985; Franx *et al.* 1991). Fig. 2 shows the preliminary distribution of Ψ in the representative sample of ellipticals observed with SAURON (de Zeeuw *et al.*, 2001). This can be compared with Fig. 17 of Franx *et al.* (1991).

4 Conclusions & perspectives

Kinemetry is a simple yet powerful and flexible technique to quantify the kinematic maps of early-type galaxies as provided by IFS. It allows filtering of the maps based on a chosen geometry of the galaxy. The next step is to extend the analysis of, e.g., Statler (1994), and work out from dynamical modeling how the various kinemetric parameters – in particular the misalignment angle Ψ and the morphology parameter c_3 – can be linked to the intrinsic shape (triaxiality) and orientation of the observed galaxy, and thus observationally constrain these quantities.

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