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Using Gaia as an Astrometric Tool for Deep Ground-based Surveys

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Abstract. Gaia DR1 positions are used to astrometrically calibrate three epochs' worth of Subaru SuprimeCam images in the fields of globular cluster NGC 2419 and the Sextans dwarf spheroidal galaxy. Distortion-correction "maps" are constructed from a combination of offset dithers and reference to Gaia DR1. These are used to derive absolute proper motions in the field of NGC 2419. Notably, we identify the photometrically-detected Monoceros structure in the foreground of NGC 2419 as a kinematically-cold population of stars, distinct from Galactic-field stars. This project demonstrates the feasibility of combining Gaia with deep, ground-based surveys, thus extending high-quality astrometry to magnitudes beyond the limits of Gaia.

Keywords. astrometry, Galaxy: kinematics and dynamics, galaxies: dwarf

1. Introduction

Deep and wide-field ground-based programs such as the Dark Energy Camera Surveys, or the upcoming Large Synoptical Survey Telescope (LSST) to name only two, will routinely produce catalogues with billions of objects. Such data will uncover sparse and distant stellar systems such as clusters, dwarf galaxies, and tidal streams and overdensities which are key to our understanding of the Galaxy and the Local Group in the current cosmological paradigm. Here, we focus on the astrometric potential of such surveys which will deliver the much needed proper motions of very faint systems. We develop a methodology to astrometricaly calibrate mosaic imagers on large telescopes, and apply it to Subaru SuprimeCam data.

2. Observational Data

SuprimeCam images covering three epochs were downloaded from the Subaru telescope archive (SMOKA) in the fields of globular cluster NGC 2419, and dwarf spheroidal galaxy (dSph) Sextans. The first two epochs consist of V-filter, 15 to 360-sec exposures. The 2012 data are in Strömgren b and y, with exposures of 18 to 360 sec. The camera underwent a major upgrade in 2008, including the installation of new detectors, therefore separate astrometric calibrations are required. Gaia DR1 positions were extracted from the web-based Gaia archive facility (Gaia Collaboration *et al.* 2016). An overview of the data is presented in Table 1. Having offset exposures is important and allows the construction of astrometric calibration maps of the field of view and each detector. The pattern of offsets and dithers is shown in Fig. 1.

3. Distortion-Correction Maps

Maps of position residuals are constructed by transforming detector coordinates of each SuprimeCam chip into Gaia DR1 positions using third-order polynomials. The ten

Table 1. Characteristics of the Observations

	NGC 2419	**Sextans**
Epochs / No. of exposures	**2002** / 207 **2005** / 48 **2012** / 22	**2005** / 62 **2012** / 60
Gaia DR1	**2015**	**2015**

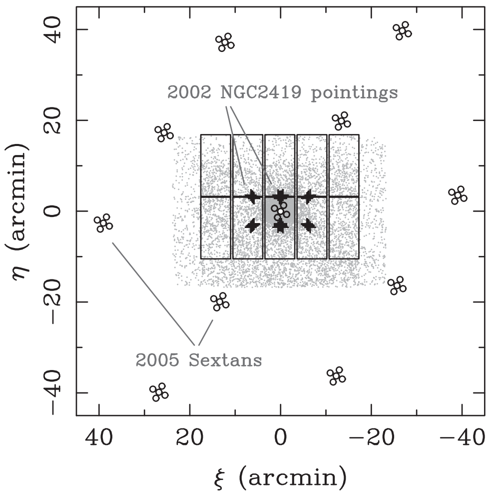

Figure 1. Dither pattern of SuprimeCam pointings in the field of NGC 2419 and Sextans. The dark frame illustrates a single exposure's field of view.

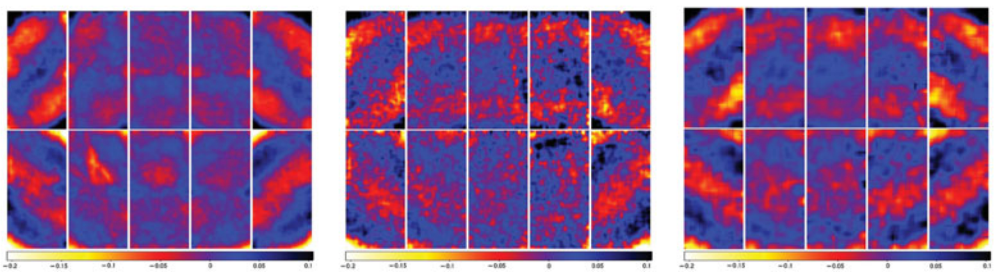

Figure 2. Distortion-correction maps, beyond third-order field terms, for SuprimeCam in 2002 (left), 2005 (middle) and 2012 (right). Corrections in the y-coordinate are shown, while those in x are generally similar. Units are pixels with a pixel scale of 0.2"/pix.

individual chips of SuprimeCam are apparent in Fig. 2, in which we display the y-coordinate maps. The 2012 data are close to the epoch of Gaia DR1 positions (2015), so these residuals can be used directly to construct a correction map (Fig. 2, right panel). Residuals from both the Sextans and NGC 2419 fields are stacked to produce this epoch's map. For the 2002 and 2005 data, the first step is a transformation into Gaia DR1, after which an average catalog at each epoch is constructed. This is followed by a transformation of each chip and frame into the appropriate average catalog; the subsequent residuals are used to construct these two epochs' maps. Averaging positions for the same object from multiple locations in the chip and field of view approximates a systematics-free average catalog. The more offsets and dithers we have, the better the average catalog.

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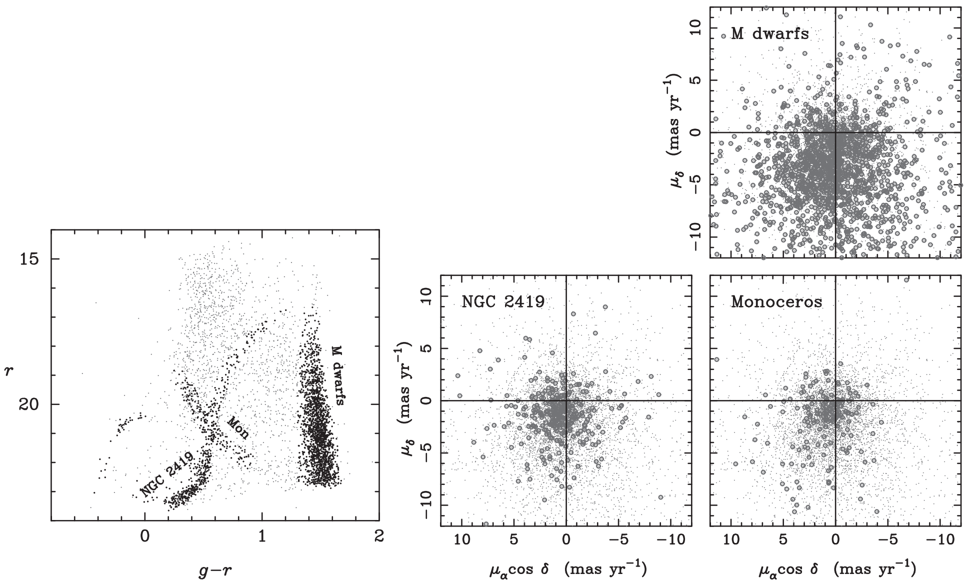

Figure 3. Left: Color-magnitude diagram in the field of NGC 2419 (beyond 5' from cluster center). NGC 2419 stars, Monoceros stars, and disk M dwarfs are highlighted and labeled. Right: Proper-motion diagrams of the three stellar populations highlighted in the left panel.

Among our data sets, those in the field of NGC 2419 for epoch 2002, and in the field of Sextans for epoch 2005, are appropriate for such mapping.

4. Preliminary Results

Preliminary proper motions are determined in the field of NGC 2419. Proper motions are on an inertial reference frame using background galaxies. The galaxies are selected using the 2002 and 2005 data classification (i.e., FWHM-based neural-network classification employed by the SExtractor code). In the foreground of NGC 2419 lies a diffuse and extended stellar system, originally discovered from SDSS data, that is referred to as the Monoceros ring, and is part of a more extended structure toward the galactic anticenter. Recently, a photometric study by Carballo-Bello *et al.* (2015) has shown a very distinctive main sequence of the Monoceros structure in the particular field of NGC 2419. Here, we use their photometry to select various stellar populations and examine their proper motions. In Fig. 3, we show the color-magnitude diagram (left) for this field, with various stellar populations highlighted, while the right panel shows the corresponding proper-motion distributions. Both cluster stars and Monoceros stars show a tight clump in proper motions, indicating kinematically cold populations, for which the scatter is dominated by our proper-motion errors. Conversely, nearby disk stars, as represented by the M dwarfs, show a large scatter that is due to the intrinsic velocity dispersion of these stars.

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