Observing, calibrating and reducing near-infrared imaging mosaics

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Abstract. In near-infrared bands, co-adding and tiling of astronomical imaging datasets require a sufficiently high calibration quality (flat fielding, background subtraction). Here we present a complete workflow for obtaining imaging mosaics with the MMT and Magellan Infrared Spectrograph (MMIRS) operated at the 6.5-m MMT in Arizona and open-source add-on tools developed for the MMIRS pipeline for preparation and data reduction of mosaic observations. We describe pre-observing actions, such as design of dithering patterns and mosaic layouts and post-processing steps to perform absolute astrometric and photometric calibration, and also generate HiPS maps to display the final data product in Aladin / Aladin Lite.

1. Introduction

Co-adding and tiling of astronomical imaging datasets allow one to investigate low-surface brightness features of extended objects such as galaxies, nebulae, comets etc. However, near-infrared CMOS detectors compared to optical CCDs contain a lot of imperfections: pixel-to-pixels sensitivity variations are high (30%) and wavelength-dependent; there is persistence from bright sources, cross-talk from different read-out channels. To overcome these difficulties, while taking a series of NIR images the telescope should slightly change it position in accordance with the chosen dithering pattern, which in many cases is a random sequence. Another difficulty comes from the night sky background level that is much higher compared to optical wavelengths and at the same time its spectral content changes spatially and temporally.

Here we present an infrared imaging survey conducted with the MMIRS instrument at the 6.5-m. MMT telescope (McLeod et al. 2012) for the Coma cluster that follows up our optical spectroscopic observational campaign carried out with the Binospec multi-object spectrograph (Fabricant et al. 2019) to study the evolution and properties of dwarf galaxies in clusters. These data are used for SED modelling of ultra-diffuse galaxies and accurate determination of their structural parameters and stellar masses (Grishin et al. 2021, 2019; Chilingarian et al. 2019).
2. Observing strategy

Typically, an imaging mosaic is taken as a set of separate images that have their own dithering patterns for each field. However, these fields are usually much closer to each other than the maximal offset size allowed by the telescope without re-acquiring the target (1 deg for the MMT). Therefore, instead of putting separate observation for each field in the telescope scheduling system, one can make one observation for several adjacent fields with a custom dithering pattern for it, which will include dithering patterns for each single field concatenated into one large single pattern. Changing the field rotator angle at a large telescope is usually much more time-consuming than short slews, therefore it is recommended to limit the number of position angle values to 2–3.

For the Coma cluster survey we split 36 fields covering the footprint of 8 Binospec slit masks into two groups with PA values of 0° (11 fields) and 340° (25 fields). 4 fields at PA=340° fill into the footprint of archival imaging datasets obtained in J and K bands with WIRCam at CFHT, so they were excluded from the dithering patterns for these bands and retained only in the H band. All fields at PA=0° were joined into one dithering pattern since they are spanning an area of the sky 14 arcmin across. Fields at PA=340° cover a larger area containing the footprint of two Binospec masks (“Coma 1” and “Coma B”) located far from the cluster center. To prevent the telescope from getting close to the dithering pattern size limit these fields were split into two patterns.

3. Data reduction

The data reduction was done using the standard MMIRS pipeline (Chilingarian et al. 2015) in the imaging mode. For each field during the reduction process the images from the other fields obtained in the same night containing no extended objects (e.g. larger galaxies) were used as offset sky images from flat field construction.

The large number of fields makes the manual preparation of pipeline configurations exhausting and increases the time investments into whole data reduction process. To automate this process we have developed a Python-based wrapper that splits the list of raw pre-processed images obtained in a each dithering pattern into a set of images that belong to a single field. For the stack co-adding, MMIRS pipeline estimates the centroid position of a reference star whose coordinates on the first image in the sequence are set manually by the user. This part of configuration preparation process was also automatised in the wrapper by applying SExtractor package on raw images and filtering its output source catalogs.

As an output pipeline provides flatfielded co-added FITS images with World Coordinate System (WCS) that came from the Telescope Control System (TCS).

4. Sky background correction

The standard data reduction includes a background subtraction where the background shape is considered flat. However, in NIR bands, especially H, the air glow has variations on a small spatial scales (several arcmin) causing the gradient of the sky background across the MMIRS 7′×7′ field of view. Given that the air grow OH emission lines may change on short (< 1 min) timescales, the co-adding of even a substantial (10...20) number of frames does not remove the sky gradient.
5. Astrometric and photometric calibration

Reduced images returned by the MMIRS pipeline contain the WCS originating the TCS which may be offset by as much as 15", so at this stage the fields cannot be tiled and the WCS correction is required. We developed a dedicated Python package that retrieves a subset from a reference astrometric catalog selected by a user from the following options: GAIA, UKIDSS (Lawrence et al. 2007), PanSTARRS and 2MASS (Skrutskie et al. 2006). For the retrieval procedure it utilizes the PyVO methods. Then, the SEXTARCTOR (Bertin & Arnouts 1996) is applied to the image to create a source catalog which is then cross-matched with the reference catalog. The pairs, containing celestial and image coordinates are used for WCS parameters determination using LMFIT package (Newville et al. 2014). This procedure is repeated with outlier rejection on each iteration until some given threshold on $\chi^2$ is reached.

For the photometric zero-point calibration our package also retrieves a subset of a reference catalog and performs the cross-match with the source catalog for the image. Then a value of the photometric zero-point is determined using a linear regression.

6. Image tiling using Hierarchical Progressive Surveys (HiPS)

For visualization and basic data analysis purposes, tiling of all 36 fields into one FITS file may not be the best solution because its size will be very large and the manipulations with such files is computationally and network-heavy. Hence, we use HiPS (Fernique et al. 2015), a multi-order HEALPix tessellation for astronomical imaging.
surveys, which can be easily viewed using Aladin desktop (Bonnarel et al. 2000) and embedded into any web-page (Fig. 2) using Aladin Lite (Boch & Fernique 2014). This visualization technique broadens the opportunities of this imaging survey to be used as a value-added dataset in many other projects, including RCSED (Chilingarian et al. 2017).

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