Astronomical Data Analysis Software and Systems XXV
ASP Conference Series, Vol. 512
Nuria P. F. Lorente, Keith Shortridge, and Randall Wayth, eds.

Mid-Infrared Astronomy with the E-ELT: Data Reduction Software for METIS

M. Mach,[1] W. W. Zeilinger,[1] R. Köhler,[2,1] O. Czoske,[1] K. Leschinski,[1], W. Kausch,[1,2] N. Przybilla,[2] T. Ratzka,[3] R. Greimel,[3] M. Leitzinger,[3] R. Ramlau,[4,6] B. Brandl,[5] M. Güdel,[1] B. Ziegler,[1] and J. Alves[1]

[1]*Department of Astrophysics, University of Vienna, 1180 Vienna, Austria*

[2]*Institute for Astro- and Particle Physics, University of Innsbruck, 6020 Innsbruck, Austria*

[3]*Institut für Physik / Institutsbereich für Geophysik, Astrophysik und Meteorologie / IGAM NAWI Graz, Karl-Franzens-Universität Graz, 8010 Graz, Austria*

[4]*Johannes Kepler University Linz, 4040 Linz, Austria*

[5]*Sterrewacht Leiden, Leiden University, 2300 RA Leiden, The Netherlands*

[6]*Johann Radon Institute for Computational and Applied Mathematics (RICAM), 4040 Linz, Austria*

Abstract. We present an overview of the on- and off-line data reduction pipeline to produce science ready data as well as quality control parameters for METIS. The paper summarizes the current status of our efforts in this project and highlights the particular challenges of developing a robust and versatile data reduction environment for an instrument of a 40 meter-class telescope.

1. Introduction

The Mid-Infrared E-ELT Imager and Spectrograph (METIS) (Brandl et al. 2014) for the European Extremely Large Telescope (E-ELT) (de Zeeuw et al. 2014) will feature diffraction-limited imaging at L/M/N/Q1 wavelengths as well as low/mid-resolution longslit spectroscopy (R ~ few hundreds – thousands), high-resolution integral-field spectroscopy (IFS) (R ~ 100,000), and coronagraphy for high-contrast imaging at L/M/N wavelengths. METIS will be equipped with state-of-the-art adaptive optics capabilities and will have a $11'' \times 11''$ field of view.

The imaging and spectroscopic modes will be surpassing the resolution of the James Web Space Telescope / Mid Infrared Instrument (JWST/MIRI) (Rieke et al. 2010) by a factor of ~ 6. This makes METIS suitable for follow up observations at high-resolution complementary to JWST/MIRI detections.

METIS will use one HAWAII-2RG 2k × 2k detector for the L/M wavelength Imager and Spectrograph, an AQUARIUS 1k × 1k detector for the N/Q1 wavelength Imager and Spectrograph and either one HAWAII-4RG 4k × 4k detector or four HAWAII-2RG 2k × 2k detectors for the L/M wavelength IFS.

The instrument will feature a parallel observing mode which harnesses the capability of acquiring L/M and N/Q imaging and/or spectroscopy frames simultaneously.

In the wavelength regime between 3 – 19 μm (L/M/N/Q1 wavelengths), data reduction is particularly challenging, as thermal radiation from the telescope itself and the Earth's atmosphere is orders of magnitude higher than the flux from the science target, which greatly increases the background noise.

Therefore, the instrument including the detectors will be completely encapsulated in a cryostat operating below 40 K in order to minimize thermal radiation.

Due to the high signal of the remaining background photons the detectors will need to be read out in timescales of sub-seconds. The data rates will vary according to the observing mode. The maximum expected data rate being delivered by the burst mode of the L/M-band Imager is at a readout rate of 20 frames s^{-1}. This leads to 170 MByte s^{-1} or 6.1 TByte per 10 hours of observation.

2. Science-Software Design

The METIS science software is designed to produce science grade data products. In addition it will be used to monitor calibration data, instrument health, data quality and quantify characteristic properties of the instrument and detector.

2.1. Pipeline Levels

The data flow system requirement by ESO is to provide various defined data reduction pipeline levels. These will be run in different locations. The first level, the observatory pipeline, will be run in Chile. Followed by the second level, quality control, in Garching. And finally the Science-Grade Desktop Environment, which is run at the user's own machine. The pipelines share most of the code to do the actual processing and will be implemented as described in the following subsections.

2.1.1. Observatory Pipeline

Raw data from the instrument are processed at the observatory in an automatic way without any user interaction. The main purpose is the derivation of Quality Control (QC) parameters for the online quality control process and monitoring of instrument health.

2.1.2. Quality Control Pipeline

The pipeline is used offline to reduce raw data taken in standard instrument modes into master calibration frames and science data products. These products are used to derive QC parameters for monitoring the instrument's performance, and to produce science data products for service-mode programmes. The calibration and science products are stored in the ESO science archive. The non-interactive operation of the pipelines at the observatory and by the Data Products and Quality Control Group in Garching will use a carefully selected set of parameters to enable robust and automatic performance of the pipeline.

2.1.3. Science-Grade Desktop Environment

The pipeline is made publicly available by ESO to external users to perform the full data reduction chain in order to obtain the best scientific grade data products. The pipeline consists of recipes for individual processing steps with adjustable parameters and an interactive data management tool and graphical front-end to the pipeline recipes.

2.2. Pipeline Data Products

2.2.1. Science data products

The science data products result from processing raw science data by applying the requisite master calibration products. Science data products are corrected for instrumental effects and converted to physical units. Error maps associated with the science data products describe the expected error for each pixel of a science frame, and masks identify bad pixels.

2.2.2. Quality Control Parameters & Master Calibration Products

QC parameters computed by the pipeline assess the data quality quantitatively and are used to track observation conditions, stability and accuracy of calibrations.

Master calibration products result from processing raw calibration data. They are used to produce QC Parameters and to process science data products.

2.3. Pipeline Structure and Implementation

2.3.1. C- Functions, CPL and HDRL

The basic units of the software are functions implemented in ANSI-C using the Common Pipeline Library (CPL) (ESO CPL Development Team 2014).

The High-Level Data Reduction Library (HDRL) is a recent project by ESO that is under active development. It is expected to provide functions to perform reduction steps that are largely instrument-independent and therefore have to be performed by all or most instrument pipelines.

2.3.2. Reflex Workflows

A sequence of recipes forms a pipeline that converts a sequence of observations into master calibration frames and science grade data products. The recipes are integrated along with data organization, classification, and association tools into a single workflow that can be executed by the user under the Reflex environment (Freudling et al. 2013). Reflex workflows may include interactive sub-workflows that enable the user to improve individual processing steps after inspecting the intermediate data products with a graphical user interface.

2.4. Data Reduction Steps

The steps that will be implemented will follow the instrument calibration plan, which is currently in the process of being worked out by the instrument, science and calibration teams within the METIS consortium. Major uncertainties exist notably for the important step of background subtraction, for which various methods are currently under investigation, and the effects of the Adaptive Optics system on the data quality.

All reduction steps will include adequate error propagation. Some of the effects that will need to be taken care of include:

- measurement and monitoring of dark current, relative pixel sensitivities and gains (flat field) and identification of bad pixels

- subtraction of sky and thermal backgrounds
- wavelength calibration for spectroscopic modes (longslit / IFS) using internal reference lamps for atmospheric emission lines
- for cross-dispersed spectroscopy the detection of orders and subsequent mapping from the 2d plane to 1d spectra
- astrometric calibration
- flux calibration
- telluric absorption correction (see Smette et al. 2015)
- reconstruction of the IFU cube
- basic data handling steps concerning the coronagraphy

The quality of observations made with METIS will largely depend on environmental parameters such as seeing, the precipitable water vapor (PWV), the temperature of the telescope structure, atmospheric transmission and its dust content. They will be written into the data file headers of the frames taken and used for data reduction. All these effects will have to be monitored in real time as most of them change on rather short timescales of minutes to hours.

3. Conclusion

The METIS data reduction pipeline will be a robust and crucial part of the instrument that will be one of the first three instruments for the E-ELT. Parts of the pipeline will transform and evolve with time until the design phase of the project ends. The outcome will be software that provides science grade data, master calibration frames and QC parameters tailored to the needs of the instrument, telescope and usability for the scientist in order to provide a reliable basis to perform scientific research using photometry, slit spectroscopy, integral-field spectroscopy, and coronagraphy in the mid-IR wavelength regime.

References

Brandl, B. R., et al. 2014, in SPIE Conf. Ser., vol. 9147, 21
de Zeeuw, T., Tamai, R., & Liske, J. 2014, The Messenger, 158, 3
ESO CPL Development Team 2014, CPL: Common Pipeline Library, Astrophysics Source Code Library
Freudling, W., et al. 2013, A&A
Rieke, G., Wright, G., Glasse, A., Ressler, M., & MIRI Science Team 2010, in American Astronomical Society Meeting Abstracts #215, vol. 42 of Bulletin of the American Astronomical Society, 439.04
Smette, A., et al. 2015, A&A, 576, A77