CARMENES: data flow

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ABSTRACT

CARMENES, the new Calar Alto spectrograph especially built for radial-velocity surveys of exoearths around M dwarfs, is a very complicated system. For reaching the goal of 1 m/s radial-velocity accuracy, it is appropriate not only to monitor stars with the best observing procedure, but to monitor also the parameters of the CARMENES subsystems and safely store all the engineer and science data. Here we describe the CARMENES data flow from the different subsystems, through the instrument control system and pipeline, to the virtual-observatory data server and astronomers.

Keywords: Site operations, data networks, computers, instrument control systems, pipelines, astronomical databases

1. INTRODUCTION

In general, scientists show their greatest interest in imposing the top-level requirements in the conceptual and preliminary design phases at the beginning of an instrumental project, and in retrieving and analysing the output data during the science exploitation phase at the end of the project. Meanwhile, optical, mechanical, electric and software engineers focus their attention in some of the intermediate steps of the project, from the preliminary and final design phases, through the manufacture, assembly, integration and verification phase, to the instrument commissioning. As a result, only a few individuals (e.g., Principal Investigator, Project Scientist, System Engineer, Project Manager) participate in all steps of the instrumental project. In the case of a complex instrument in which the science results are sensitive to tiny variations in any of the different subsystems, an end-to-end supervision of the data flow is indispensable.

CARMENES stands for Calar Alto high-Resolution search for M dwarfs with Exoearths with Near-infrared and optical Echelle Spectrographs. It is an ultra-stabilised double-channel spectrograph that covers in one shot from 0.52 μm to 1.71 μm with a spectral resolution greater than 80,000 (Quirrenbach et al., this volume). Its front-end is installed in the Cassegrain focus of the 3.5 m Zeiss telescope of the Calar Alto observatory (Centro Astronómico Hispano-Alemán, CAHA) in Almería, in the south of Spain. Its two fibre-fed spectrographs, dubbed VIS and NIR, are inside climate

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chambers in the 3.5 m telescope coudé room, together with the vacuum, cooling and wavelength calibration systems, and the main computers. To date, CARMENES is the only precise high-resolution double spectrograph with a wide wavelength coverage in both optical and near infrared that delivers ~1 m s^{-1} radial-velocity precision (some on-going projects with the same goal are GIARPS = GIANO+HARPS-N at the 3.6 m Telescopio Nazionale Galileo in La Palma, NIRPS+HARPS-S at the 3.6 m ESO telescope in La Silla and, at a longer timescale, HiRes at the 39 m European Extremely Large Telescope).

CARMENES was designed and built by the eponymous CARMENES consortium, which consists of ten astronomical research centres and universities in Spain and Germany and the Spanish-German Calar Alto observatory. This relatively large number of consortium members with different expertises (e.g., near-infrared detectors, vacuum and cryogenics, interlocks, instrument control system, scheduling, data pipelining, archiving) translated into numerous interfaces between subsystems, which required a close and constant monitorisation by a small team of astronomers and engineers during the design, MAIV and commissioning phases.

The instrument complexity is illustrated by the list of 15 CARMENES computers (including main and spare) in Table 1. The CARMENES computers are named after astronomers that (have) contributed significantly to the discovery of M dwarfs[1]. All of them run on Linux openSUSE 12.3 64 bits, except the NIR computer, which runs on Linux openSUSE 13.1 64 bits.

Table 1. List of CARMENES computers at the Calar Alto observatory.

Computer	Task	Model	Location
ICS Lab (luyten)	ICS GUI, web (CAHA weather, finding charts, Carmencita, Simbad, ADS, skype)	Dell OptiPlex 7010 MT desktop, i7 Quad Core, 1TB storage	Remote observing room
ICS One (gliese) ICS Two (jahreiss)	Instrument control and monitoring, scheduling, nightly spectra storage	Dell PowerEdge R420 rack server, 2x Intel Xeon E5-2430 v2 (6 cores, 2.5GHz), 2TB internal storage + 2TB external storage, 16GB RAM, 1U rack chassis	Coudé room main rack
NIR pipe Lab (lacaille) VIS pipe Lab (kapteyn)	Pipeline GUIs, night logs, wiki	Dell OptiPlex 9020 MT desktop, i5 Quad Core, 500GB storage, 8GB RAM	Remote observing room
NIR pipeline (lalande) VIS pipeline (barnard)	First pipeline (CARACAL)	Dell PowerEdge R420 rack server, 2x Intel Xeon E5-2430 v2 (6 cores, 2.5GHz), 2TB storage, 16GB RAM, 1U rack chassis	Coudé room main rack
NIR comp (ross x2)	GEIRS/NIR detector and readout, NIR exp-meter, NIR fibre shaker	Dell PowerEdge R720 rack server	NIR rack
VIS comp (wolf x2)	VIS detector, VIS exp-meter, VIS fibre shaker, VIS shutter in front-end	Dell PowerEdge R420 rack server	VIS rack
A&G comp (giclas x2)	A&G camera control	cirrus[7] nimbus	Front-end
Interlocks (struve x2)	Alarms display, Scada/Mango access and control of pumps	Dell OptiPlex 7010 desktop, i5 Quad Core, 3.2GHz, 8 GB RAM, 1TB storage	Coudé room main rack

[1] N.-L. de Lacaille (1713), J. J. L. de Lalande (1732), F. G. V. von Struve (1793), J. C. Kapteyn (1851), E. E. Barnard (1857), M. Wolf (1863), F. E. Ross (1874), W. J. Luyten (1899), H. L. Giclas (1910), W. Gliese (1915), and H. Jahreiss (1942).

This contribution deals with the CARMENES data flow, where "data" here stands for any collection of alpha-numeric or Boolean values that are needed for the final scientific result, which for our guaranteed time observations (GTO) is the discovery and characterisation of exoplanets around nearby, cool, dwarf stars of M spectral type. Some of these planets may have masses and radii similar to the Earth's, and may be as well inside the habitable zones around their host stars. This contribution is complementary to other ones presented by CARMENES members in SPIE Astronomical Telescopes and Instrumentation 2016, such as the general instrument overview by Quirrenbach et al. (*9908-38*) and descriptions of the VIS channel by Seifert et al. (*9908-231*), the NIR channel by Becerril et al. (*9910-32*), and project management and system engineering by García-Vargas et al. (*9911-24*) and Pérez-Calpena (*9911-78*). This data flow description is inseparable from the CARMENES contributions on interlocks by Helmling et al. (*9908-237*) and, especially, instrument control software by Colomé et al. (*9913-149*).

2. DATA FLOW

2.1 Input catalogue (Carmencita)

Carmencita, the CARMEN[ES] Cool star Information and daTa Archive, is the M-dwarf database from where we chose our best target sample (Caballero et al. 2013; Quirrenbach et al. 2015). As part of our GTO project, about 300 late-type M dwarfs are monitored by CARMENES from Calar Alto during at least 600 nights in the 2016-2018 timeframe (García-Piquer et al. 2016). Carmencita catalogues over 2000 carefully-selected M dwarfs northern of $\delta = -23$ deg. For each star, we tabulate dozens of parameters (accurate astrometry, spectral typing, photometry in 20 bands from the ultraviolet to the mid-infrared, rotational and radial velocities, X-ray count rates and hardness ratios, close and wide multiplicity data and many more) compiled from the literature or measured by us with new data. Carmencita is perhaps the most comprehensive database of bright, nearby, M dwarfs (Fig. 1).

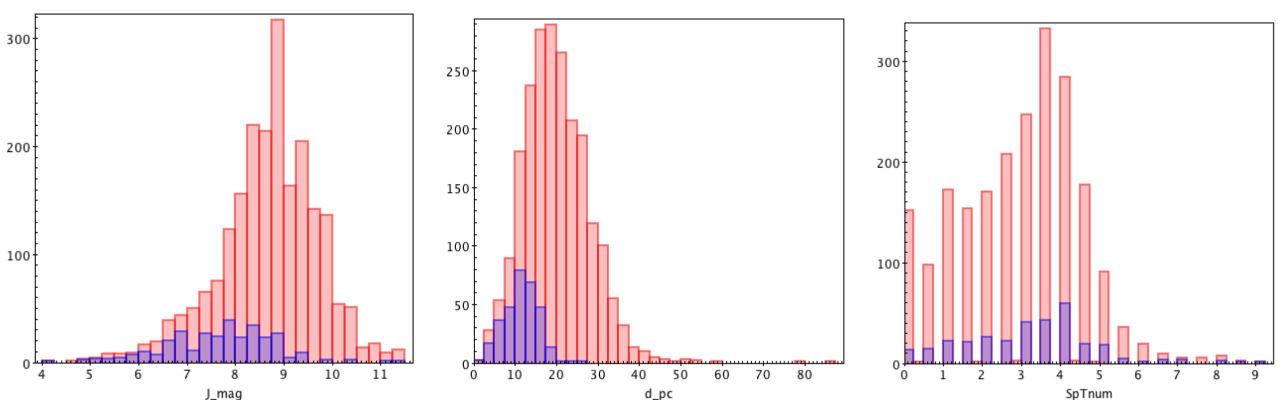

Figure 1: Distribution of *J* magnitudes (left), heliocentric distances (centre) and spectral types (right) of the ~2200 Carmencita stars (red) and the ~300 GTO targets (blue). Mean magnitudes, distances and spectral types of the GTO sample are 7.7 mag, 11.6 pc and M3.0 V, respectively.

As illustrated by Fig. 2, Carmencita is fed by a number of literature sources (Joy & Abt 1974; Lee 1984; Bidelmean 1985; Henry et al. 1994; Reid et al. 1995; Scholz et al. 2005; Lépine & Gaidos 2011; Lépine et al. 2013, etc.), public all-sky surveys (Perryman et al. 1997; Mason et al. 2001; Skrutskie et al. 2006; Roeser et al. 2010) and our own preparatory observations with FastCam/1.5 m TCS (high-resolution imaging), CAFOS/2.2 m CAHA (low-resolution spectroscopy), FEROS 2.2 m La Silla, CAFÉ/2.2 m CAHA, HRS/9.4 m HET (high-resolution spectroscopy).

All the stars and their parameters are methodically ingested into an ascii file saved with the `csv` extension for internal distribution, and visualisation and analysis with virtual observatory tools, such as TopCat. During the science preparation phase (2009-2015), the CARMENES science working group also had access to Carmencita through a website created to access a relational database in a server, located in Madrid (UCM), running on Mac OS X Mountain Lion 10.8.5 with `MySQL 5.6`. The website consisted of a collection of HTML and PHP 6.0 codes that recovered data from the original ascii input catalogue, and allowed basic searches (by coordinates, spectral types, magnitudes and previous observations).

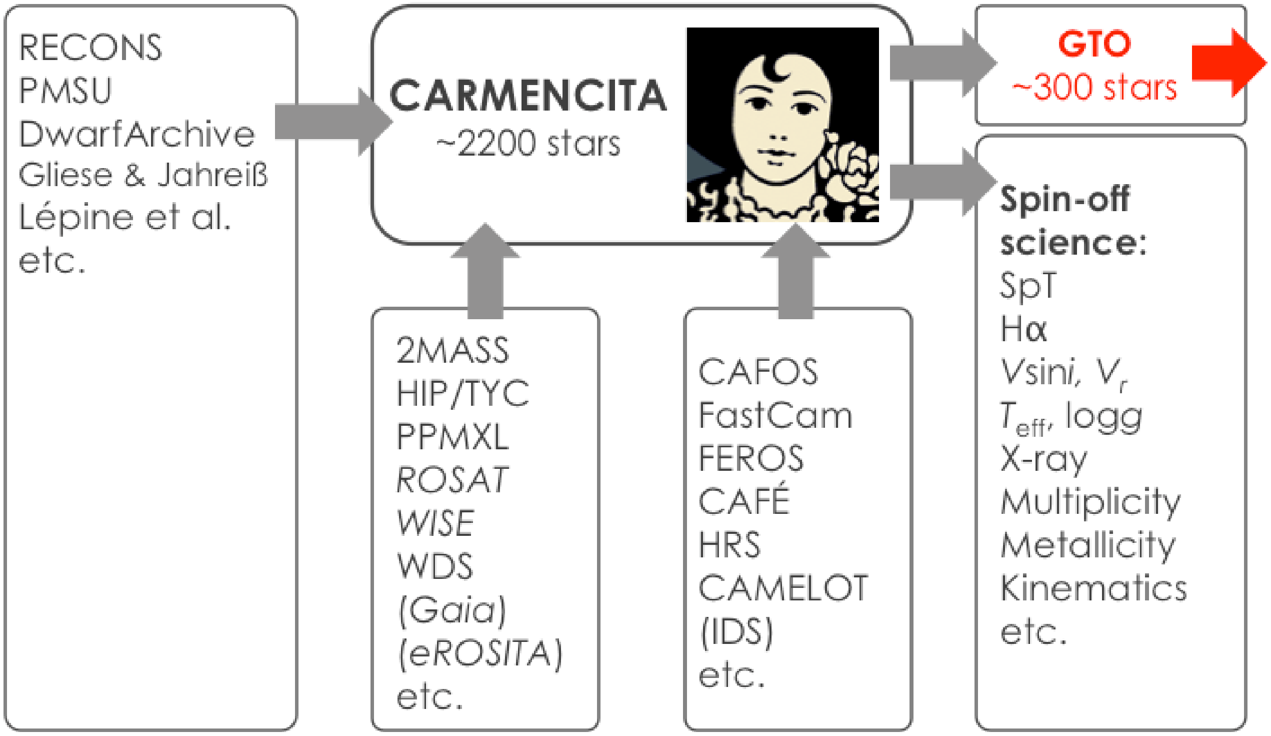

Figure 2: CARMENES data flow. I. Input catalogue (Carmencita). The data flow continues in Fig. 3.

The private catalogue, including preparatory science observations, is being made public as a CARMENES legacy through VizieR and a spin-off series of refereed papers on activity, multiplicity, basic astrophysical stellar parameters and kinematics (e.g., Alonso-Floriano et al. 2015; Cortés-Contreras et al. 2016).

The approximately 300 brightest Carmencita M dwarfs for each spectral subtype without any companion at less than 5 arcsec, either bound or unbound, feed the CARMENES scheduler.

2.2 Scheduler, Instrument Control System and Graphical User Interface

The CA[RMENES] Scheduling Tool, CAST, takes into account observational constraints and distributes the available telescope time with genetic algorithms amongst the ~300 targets of the GTO survey. CAST provides the observer, through the Instrument Control System (ICS) Graphical User Interface (GUI), with the best M dwarf to be monitored next. The CAST main parameters are visibility, elevation, Moon phase and separation, dome and telescope variables, weather, and the most basic star parameters (coordinates, spectral type, magnitude[s], weights assigned by the Project Scientist). The CAST goals are to minimise the overhead time and maximise the exoplanet yield (García-Piquer et al. 2014, 2016). The scheduler is only available for GTO observations.

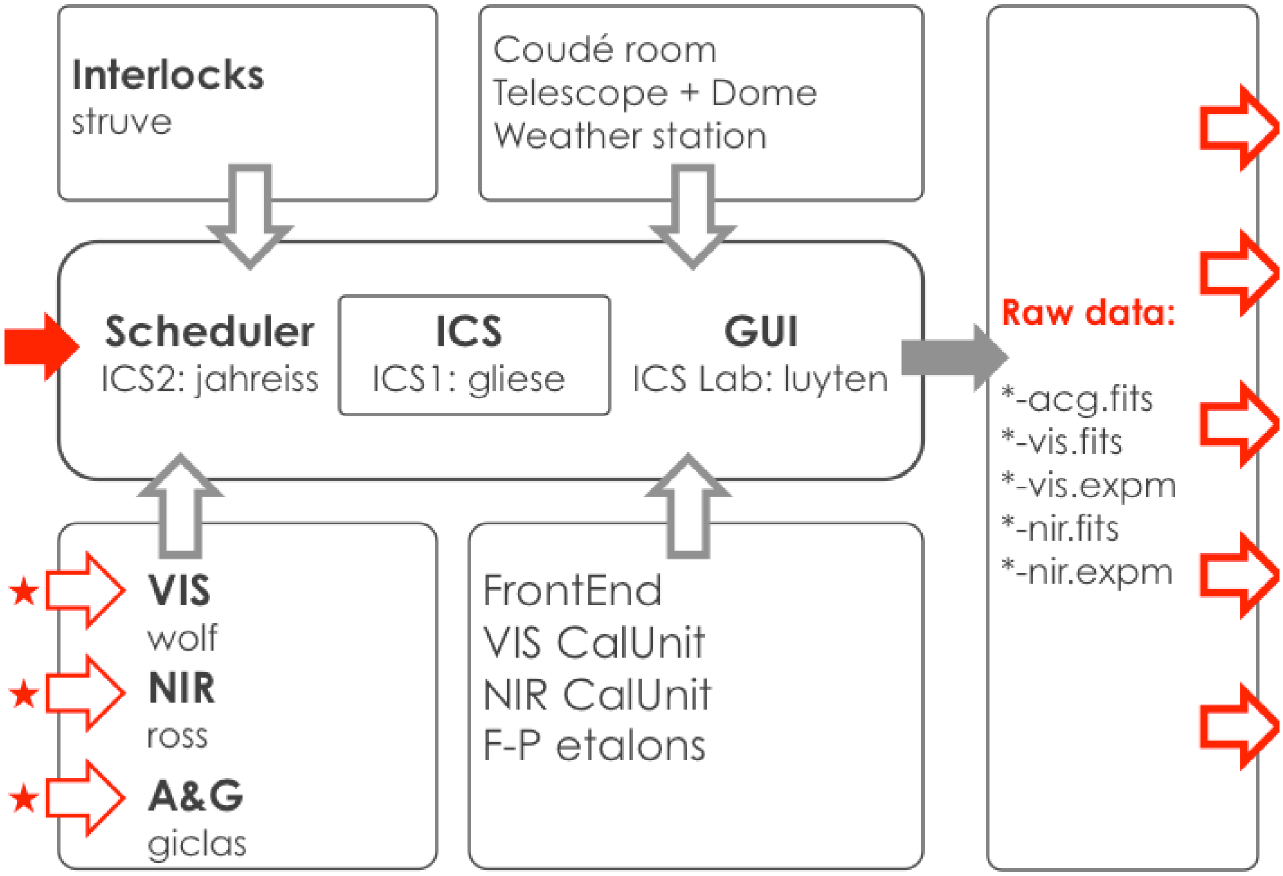

Figure 3: CARMENES data flow. II. Scheduler, Instrument Control System, Graphical User Interface, raw data and FITS headers. The data flow continues in Fig. 5.

The CARMENES ICS, which coordinates and manages the operations of the different subsystems, is described in detail by Colomé et al. (*9913-149*). In short, the ICS monitors and commands the computers of the VIS and NIR channels and the acquisition and guiding system (Table 1), and the controllers of the front-end, VIS and NIR calibration units and Fabry-Pérot etalons, interfaces with the telescope and dome, and passively receives data from the interlocks computer, coudé room and observatory weather station (Fig. 3). The heart of the system is composed of three computers: "ICS One", which runs the ICS and interacts with all the subsystems, "ICS Two", which runs the scheduler, and "ICS Lab", which runs the GUI. The two formers have FTP servers and can run the ICS and scheduler in case of fail of one of the computers, while the latter is the interface with the observer in the remote observing room. The ICS logs the full parameter status of all the CARMENES subsystems with an interval of frequencies that range to less than one minute for the weather station, to one second for the exposure meters.

The GUI is designed to be as simple and friendly as possible, for easy using by any observer (Fig. 4). Since early April 2016 (three months after the survey start), night observations are usually carried out in service mode by technical staff of the Department of Astrophysics of the Calar Alto observatory, with frequent (on-site and on-line) support from experienced individuals of the consortium. Given the small number of movable parts and fixed instrument configurations, observing with CARMENES requires a very short training.

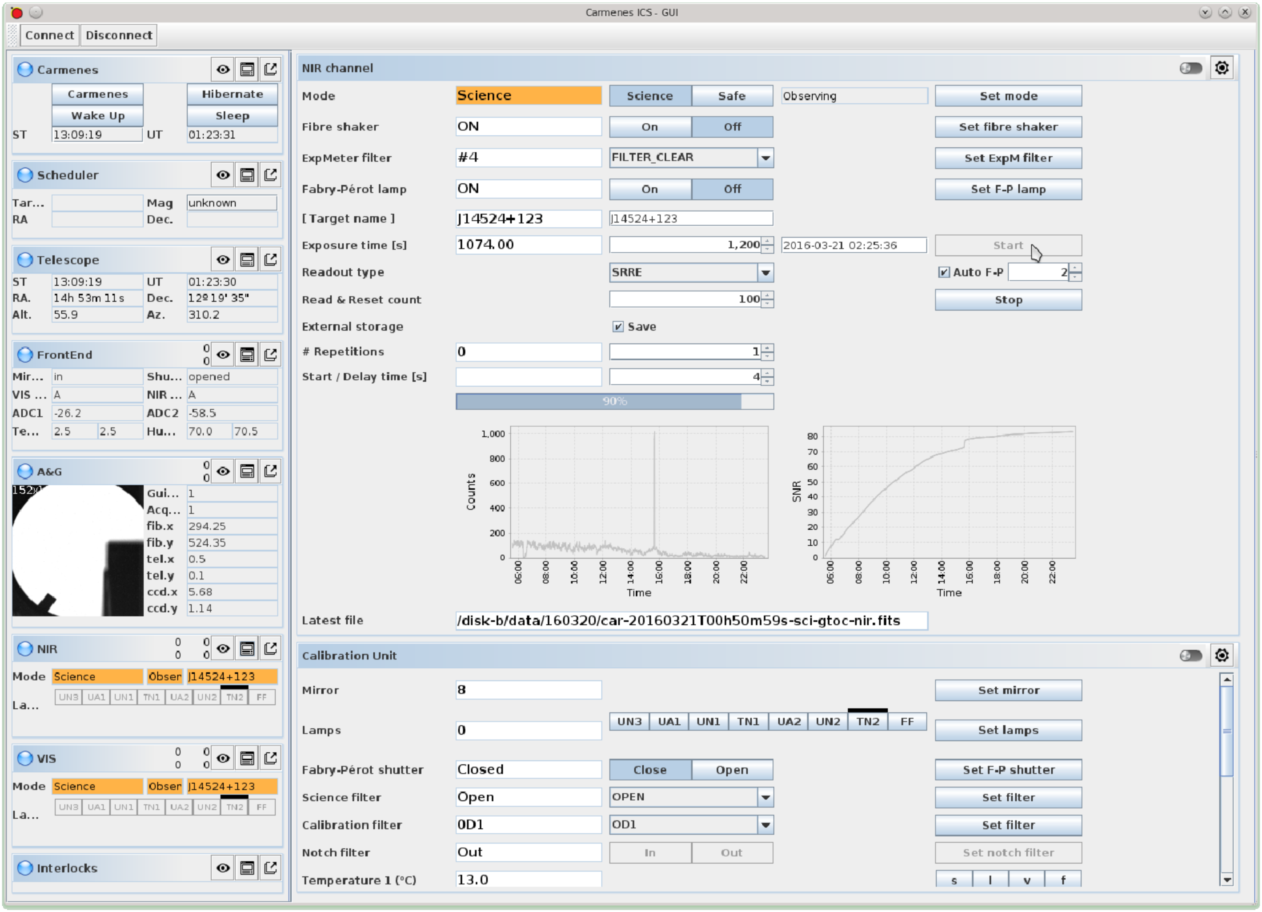

Figure 4: A capture of the CARMENES ICS GUI (example: NIR channel tab). At the moment of writing these lines, we are introducing tiny changes in the appearance and functionalities of the GUI, such as the control of two new Fabry-Pérot shutters installed in June 2016 or the option of executing observing blocks limited by signal-to-noise ratio instead of by exposure times.

2.3 Raw data and FITS headers

The output of an observing block (an "exposure") is a set of five files per target and epoch of observation: acquisition image (`*-acg.fits`), VIS spectrum (`*-vis.fits`), VIS exposure-meter count rate (`*-vis.expm`), NIR spectra (`*-nir.fits`) and NIR exposure-meter count rate (`*-nir.expm`). The channel exposure meters consist each of an off-axis parabollic mirror that collects the light of the zeroth order of the respective échelle grating, a fibre that carries that light to the channel rack, and a (visible or near-infrared) photo-multiplier. The exposure-meter files are ascii files containing time, flux and position of the exposure-meter filter. The VIS and NIR photo-multipliers are read every second.

All output files share a common string such as `car-yymmddThh:mm:ss-xxx-yyyy-*`. It indicates the instrument (CARMENES), year, month and day, hour, minute and second of start of observing block in Universal Time, image type (`sci`: science, `cal`: calibration, `tst`: test), and four-character programme code as defined by the observatory (in open time: three first characters of surname and first character of name, e.g. `cabj` for the first author of this contribution). The three FITS files have comprehensive headers provided by all subsystems. We provide the exhaustive example of the template of FITS headers for the VIS channel as an appendix at the end of this contribution.

2.4 First pipeline (CARACAL)

During standard operation at night, CARMENES simultaneously gets light from a target in the first (science) fibre and the corresponding Fabry-Pérot etalon in the second (calibration) fibre. However, it can instead get light from the sky in the second fibre when the target is faint, or light from U-Ne, Th-Ne and U-Ar hollow cathode lamps or a flat-field halogen lamp in one or two fibres for calibration.

A few seconds after the end of the observing block and spectra readout, CARACAL (CA[RMENES] Reduction And CALibration software; Zechmeister et al. 2015) automatically makes the dark/bias correction, order tracing, flat-relative optimal extraction (FOX; Zechmeister et al. 2014) and wavelength calibration (Bauer et al. 2015) of the VIS and NIR spectra, and generates fully reduced, wavelength-calibrated 1D spectra. CARACAL also provides a rough estimate of the target radial velocity based on a comparison with a high-resolution synthetic stellar model of low effective temperature and main-sequence gravity and a series of quality-control parameters for each night (e.g., CCD readout noise and gain, mean flux of the calibration lamp spectra, median resolution, absolute radial-velocity drift). Recently, we have implemented a new functionality that makes a coarse instrument-response correction and merges all the orders in a single matrix containing wavelength, flux, error in flux and background values (useable for science cases in which ultra-precise radial velocities are not necessary). In the case of the NIR channel only, there is an intermediate stage, run in the NIR computer, that pre-processes the individual GEIRS frames obtained in sample-up-the-ramp mode and generates a single frame that can be read by CARACAL.

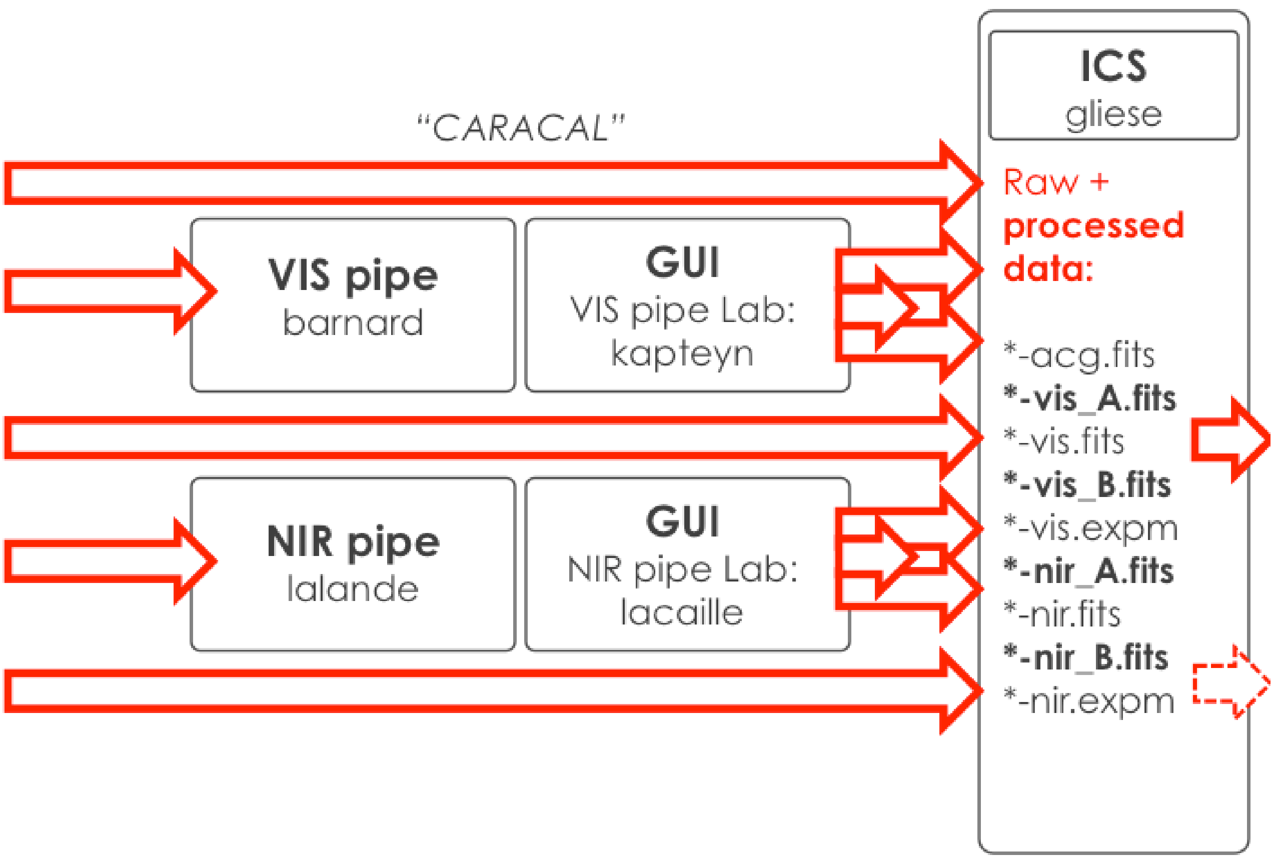

Figure 5: CARMENES data flow. III. First pipeline (CARACAL). The data flow continues in Fig. 7.

The basis of CARACAL was the IDL REDUCE package developed by Piskunov & Valenti (2002), to which many scripts have been added or some parts modified. The CARACAL package uses `IDL v6.3`, `inotify`, `xterm`, `ds9`, `gnuplot`, `Tk/Tcl 8.5`, `git` and, for miscellaneous tasks, `latex2html`, `gps`, `imhead` and `ech2dat`. We have two dedicated servers for the spectra extraction, one for each channel ("VIS pipe" and "NIR pipe" in Fig. 5); as in the case of the ICS computers, one server can run the two extraction pipelines simultaneously. We have another two desktops ("VIS pipe Lab" and "NIR pipe Lab" in Fig. 5), which are located near the the ICS Lab one with the ICS GUI, run the pipeline GUIs (dubbed `xpipe`) and display the extracted spectra in real time.

In trigger mode, CARACAL waits for new raw files that are provided by the ICS and located in the nigh folder path `/disk-b/data/yymmdd/` in ICS One (or ICS Two). The raw FITS files (science and calibration spectra) are automatically processed by CARACAL but are not modified. From the exposure-meter files, CARACAL computes the effective mean time of observation – flux weighted. All information needed for the data reduction is passed via FITS header keywords (e.g., calibration type).

The calibration and data reduction products are stored in separate directories in the pipeline servers. For each observing block, CARACAL generates four processed files, two for each channel, and one for each of the two fibres in the field of view of the acquisition and guiding system (science and calibration). The processed data are copied back to the same night directory in the ICS One computer, were we temporarily store the nine files (five raw, four processed) per observing block.

2.5 Observatory repository (CAHA Archive)

In the following morning, all files stored in the previous night folder are copied to a repository common to all instruments at the CAHA Observatory. In this proceeding, we use the name "CAHA Archive" for this repository, but it should not be confused with the "SVO Calar Alto Archive", which contains both raw and science-ready public data (after proprietary time), was designed in compliance with the standards defined by the International Virtual Observatory Alliance, was built and is maintained by the Spanish Virtual Observatory, and is located in Madrid[2] (Solano et al. 2012).

The current CAHA Archive is an evolution of a system initiated in 2010, which was designed under the principles of flexibility, reliability, robustness, security access, data storage, and hardware and software modularity and scalability. In the last years, the CAHA Archive has been deeply modified for optimising and adapting it to the requirements and features of the CARMENES operations. The CAHA Archive provides a large centralised storage capacity, data validation and back-up, nomenclature unification and a system for distributing the generated data to the principal investigator of the corresponding programme.

The three main hardware elements of the CAHA Archive are:

- *Server*. Dell PowerEdge R520 with two processors Intel Xeon E5-2407 2.40GHz Quad-Core, 32GB DDR3 RAM, a PERC 810 RAID controller with two 146GB 15K SAS discs configured as RAID1, and two hot-plug redundant power supplies.
- *Discs array*. Dell PowerVault MD1000 with 15 × 2TB SATA disks (effectively 24TB RAID), and redundant power supply. The discs array is connected to the server through a SAS Host Bus Adapter cable and Dell SAS 5/E PCIe HBA Controller Cards.
- *Network connection*. Two 1Gb/s net interfaces in bonding mode, which provide high-speed access and avoid bandwidth problems due to multiple server access.

We plan to periodically increase the storage capacity of the CAHA Archive. For guaranteeing enough capacity for the expected long operations lifetime of CARMENES, the next extension will contain another storage array of about 90TB.

Over this hardware it is running a customised software developed with `Python 2.6` and based on a `MySQL 5.0` database, `pyfits 3.3` libraries and SUSE Linux Enterprise Server 11 (x86_64). The interactive side of this system uses `Apache 2.2` and `PHP5` to provide a web interface to the operator for manual interaction in the open/capture/classify/close process. There is also an FTP server for making data accesible to the principal investigator.

[2] `http://caha.sdc.cab.inta-csic.es/calto/`

The core of CAHA Archive operations is a Python daemon that waits for a trigger for starting capturing observing block data defined by date/path/instrument/telescope. First, for CARMENES, the daemon determines which of the two ICS servers is active for data capturing (generally, ICS One). Next, it generates a thread for getting, storing, classifying and distributing all the FITS spectra (raw and reduced) and attached files (A&G image, exposure-meter files) found in the path of the active server.

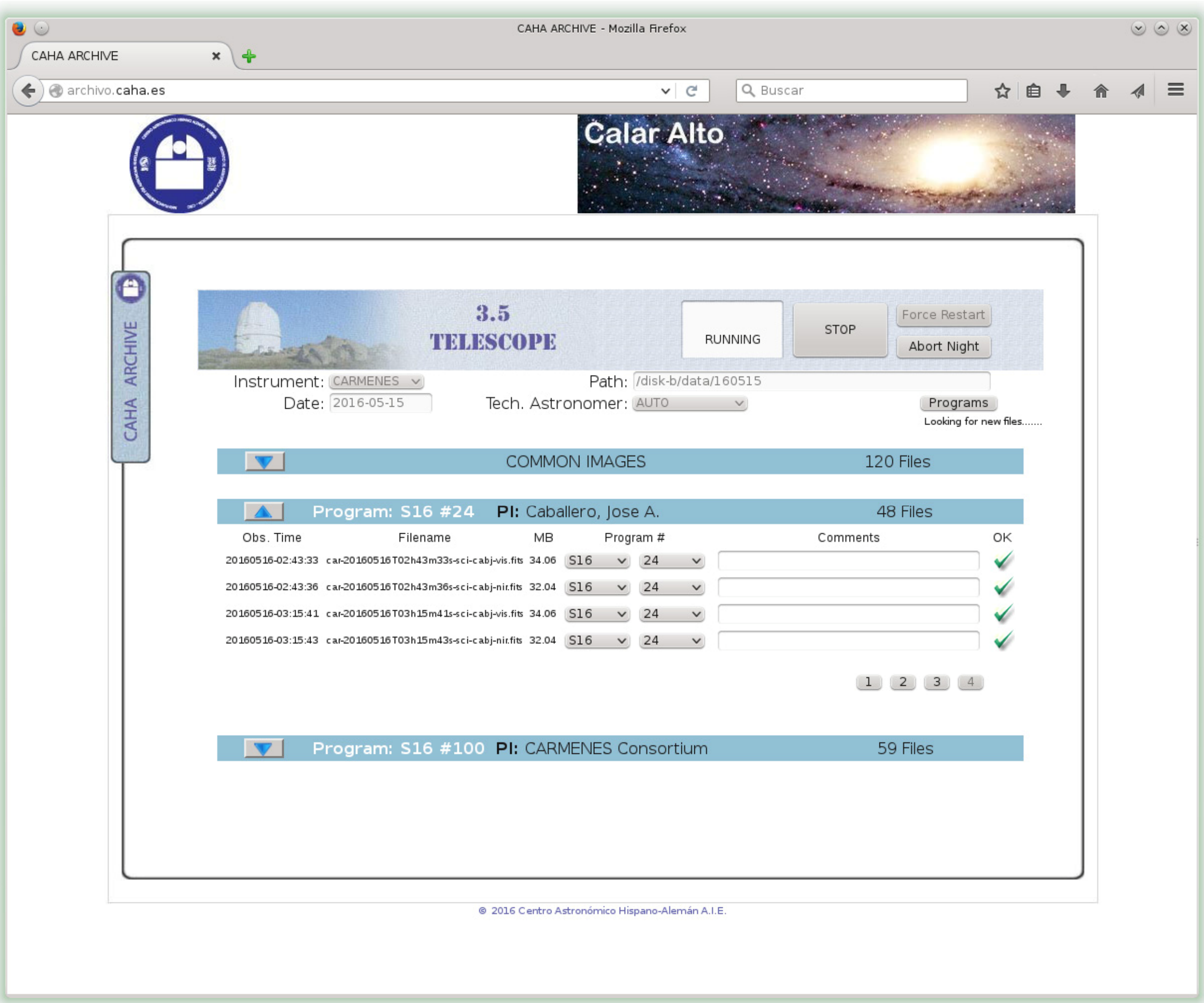

Figure 6: Operational view of a running CAHA Archive process.

The trigger is set automatically at 08:00 UT of the next morning (if it has not been started manually earlier). Although the CAHA Archive can be running during night observations and get the files as soon as they are written in the folder, the automatic trigger set avoids the CAHA Archive server to get slow when the bandwith is more necessary (at night). The possibility of manually starting the capture and making a classification of spectra is available to the night observer through a secure website (Fig. 6). This possibility will provide flexibility for adapting to errors or special situations. When one of these threads is activated, it starts a cyclic procedure by which the CAHA Archive:

- Looks for new files in the path of the night folder (the same as for CARACAL: `/disk-b/data/yymmdd/`).

- Discards images saved previously.
- Downloads only new files using FTP.
- Checks files and gets necessary headers necessary for archiving: `NAXIS`, `NAXIS1`, `NAXIS2`, `FILENAME`, `OBJECT`, `DATE-OBS`, `EXPTIME`, `RA`, `DEC`, `EQUINOX`, `PROG-NUM`, `PROG-PI`, `OBSERVER` and `HIERARCH CAHA INS ICS IMAGETYP`. The system does not try to fix header keywords or rename FITS files (during commissioning and early phases of science surveys, a few bugs in the data flow were still present).
- Stores new FITS files and registers them in the MySQL database,
- Classifies the FITS files and assigns them automatically to its observation program. The ascii exposure-meter files are associated to the FITS files based on the common part of the file name. All the daily calibration files are assigned by default to the "Common programme", which is the way to assign files to all observation programmes executed on the same night. Another special option called "No program associated" is used when the system cannot classify automatically a file.

The length of each cyclic procedure depends on the number and size of the files generated per night, ranging from a few minutes to more than half an hour. At the end of the procedure, it checks if a "close archive" flag is active. When the procedure was started autonomously, this flag is set automatically 30 min after receiving the last file (the flag will also be able to be set manually using the web interface). If the flag is inactive, the cyclic procedure goes on.

When the "close archive" flag is active, the system identifies the observation programmes developed that night, sends by automatic email to the corresponding principal investigator with an FTP user account, a password and the instructions for retrieving the data (only on the first night that data were collected for his/her programme), and connects to the Calar Alto observatory FTP server (`ftp.caha.es`). With his/her password, the principal investigator can easily download the data sorted by night folders in his/her personal area in the FTP. The CAHA Archive manages automatically the FTP server by creating/announcing/destroying accounts and distributing the corresponding data.

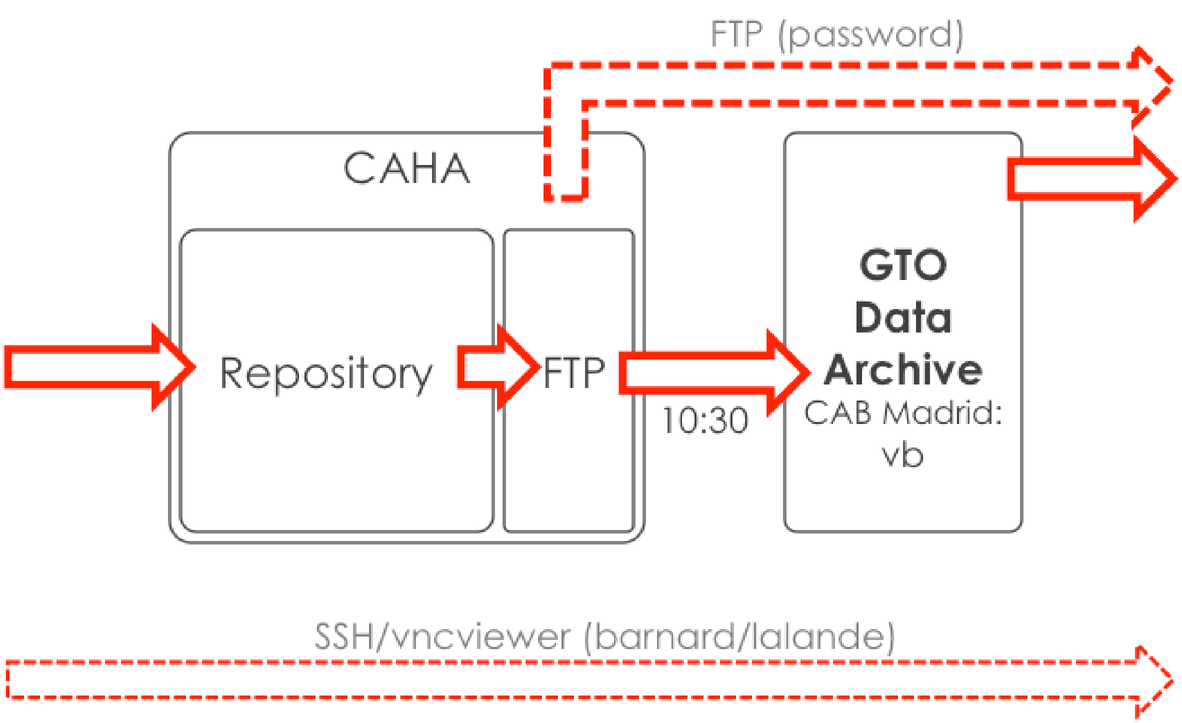

Figure 7: CARMENES data flow. IV. CAHA Archive (observatory repository) and Guaranteed Time Observations Data Archive. The data flow continues in Fig. 9.

The described archiving, triggering and data retrieval by FTP is common to guaranteed, open and director discretional time observations with CARMENES. However, there are some differences in the GTO data flow starting from this point. First, only the principal investigator of the open and director discretional time observations receives in the morning of every observed night an automatic email with the status report of his/her programme (this email is independent of the CAHA Archive). For GTO data, we implemented a synchronisation process between the CAHA Archive in Calar Alto and the GTO Data Archive in Madrid, which is automatically triggered at 10:30 UT *every day*. Since CARMENES is scheduled for about 90% of the available time of the 3.5 m Zeiss telescope, and we take calibration sequences in the afternoon even when CARMENES is not scheduled, the synchronisation is executed seven days per week, 365 days per year.

Open and director discretionary time data will be made public after one year of proprietary time through the "SVO Calar Alto Archive" (cf. Solano et al. 2012). The propietary time of GTO data is up to three years. National guaranteed time data may never be public.

After five months since the start of the CARMENES science operations on 2016 Jan 01, the CAHA Archive has digested more than 25,000 raw FITS files (`*_acg.fits`, `*_vis.fits` and `*_nir.fits`), 17,000 reduced FITS spectra and 25,000 exposure-meter files, amounting to about 900GB of data corresponding to five different CARMENES programmes (GTO, three open time, one director-discretionary time).

For speeding up the process and solving a problem of the NIR and/or VIS pipelines not running automatically every night, we implemented a third way of retrieving CARMENES data, only feasible by SSH or `vncviewer` by the manager of the pipeline computers in Göttingen. Once all the data are homogenously re-processed with the latest version of the CARACAL pipeline, the reduced data are then sent by FTP from Göttingen (IAG) to the GTO Data Archive in Madrid (CAB), which makes them available to all the members of the CARMENES Consortium.

2.6 Guaranteed Time Observations Data Archive

The CARMENES GTO Data Archive[3], hosted by the Spanish Virtual Observatory in Madrid (CAB), provides easy and reliable access to raw and processed data obtained during guaranteed time observations. This provision is through a friendly web browser interface (Fig. 8). The core of the GTO Data Archive is a server developed with free tools, mostly `Java`, `Hibernate` and `PostgreSql`, running on a desktop[4] with Ubuntu 14.04.1 LTS. It provides a login mechanism with three access levels (public data, consortium, administrator) and the capability to search data by target name (Carmencita identifier; Quirrenbach et al. 2015) or by range of nights. The system automatically analyses and shows only the available data sorted by channel (VIS, NIR), type (calibration, science) and/or processing completion (raw, reduced). FITS headers are available for all users in ascii format. Data can be downloaded as FITS files (single files) or as a zip file (multiple files).

2.7 Second pipeline (SERVAL)

An exclusive GTO step in the CARMENES data flow, SERVAL is a second pipeline that runs in Göttingen (IAG) and computes series of ultra-precise radial-velocity measurements of the ~300 monitored M dwarfs via least-square fit, template co-adding, telluric masking and proper échelle order weighting. SERVAL also measures differential full-width half maxima, chromatic indicators and the pseudo-equivalent widths of Hα λ6562.8 Å. It has the power to implement new modules that measure other spectral activity indicators (indices of the calcium triplet and sodium doublet, emission lines in the near infrared, rotational velocities). It will be described in detail by Zechmeister et al. (in prep.).

[3] `http://carmenes.cab.inta-csic.es`
[4] It is named `vb` after G.-A. van Biesbroeck (1880).

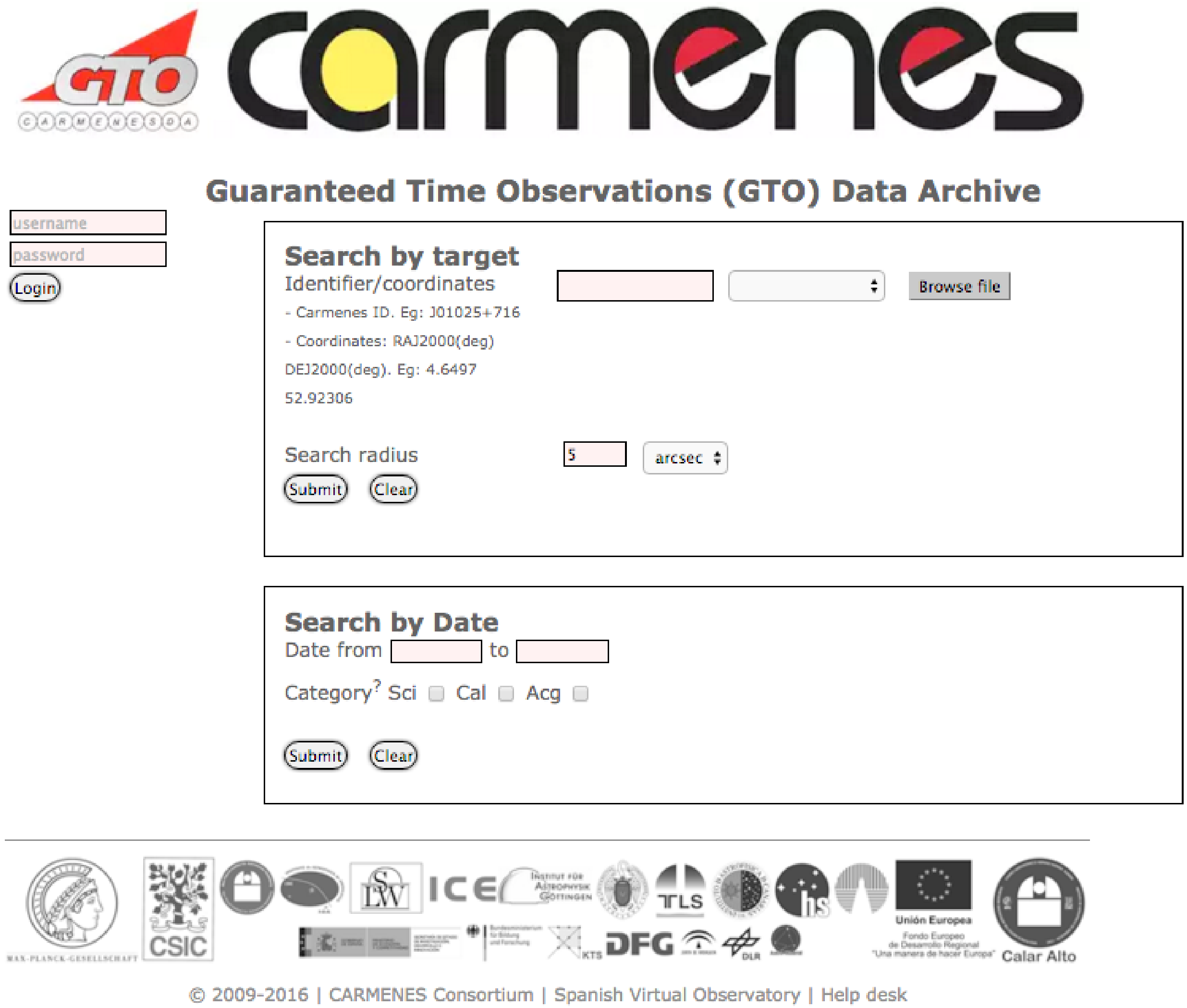

Figure 8: Capture of the home webpage of the CARMENES GTO Data Archive.

2.8 Radial-velocity data archive (RADAR) and visualisation tool (CAVEMAN)

The output of SERVAL is injected into RADAR, the RAdial velocity Data ARchive, which can be visualised by CAVEMAN, the CA[RMENES] Visualisation, Evaluation and Multi-Analysis Notebooks. Both the RADAR archive and the CAVEMAN code repository are developed in Heidelberg (MPIA) and based on Apache Subversion[5]. Besides, CAVEMAN makes use of Jupyter Notebook[6] to provide data visualisation and analysis routines. RADAR and CAVEMAN are web-based tools designed for storing and working with data generated not only by SERVAL, but also by the leaders of some internal CARMENES science work packages (Fig. 9). While RADAR is mostly a database, CAVEMAN uses the data products stored by RADAR and provides users with standard and customisable sets of visualisation and analysis procedures with the final aim of detecting and characterising radial-velocity exoplanet signals, and disentangling them from stellar activity. Closing the loop of data flow, RADAR and CAVEMAN need some of the parameters originally tabulated by Carmencita.

[5] http://subversion.apache.org
[6] http://jupyter.org

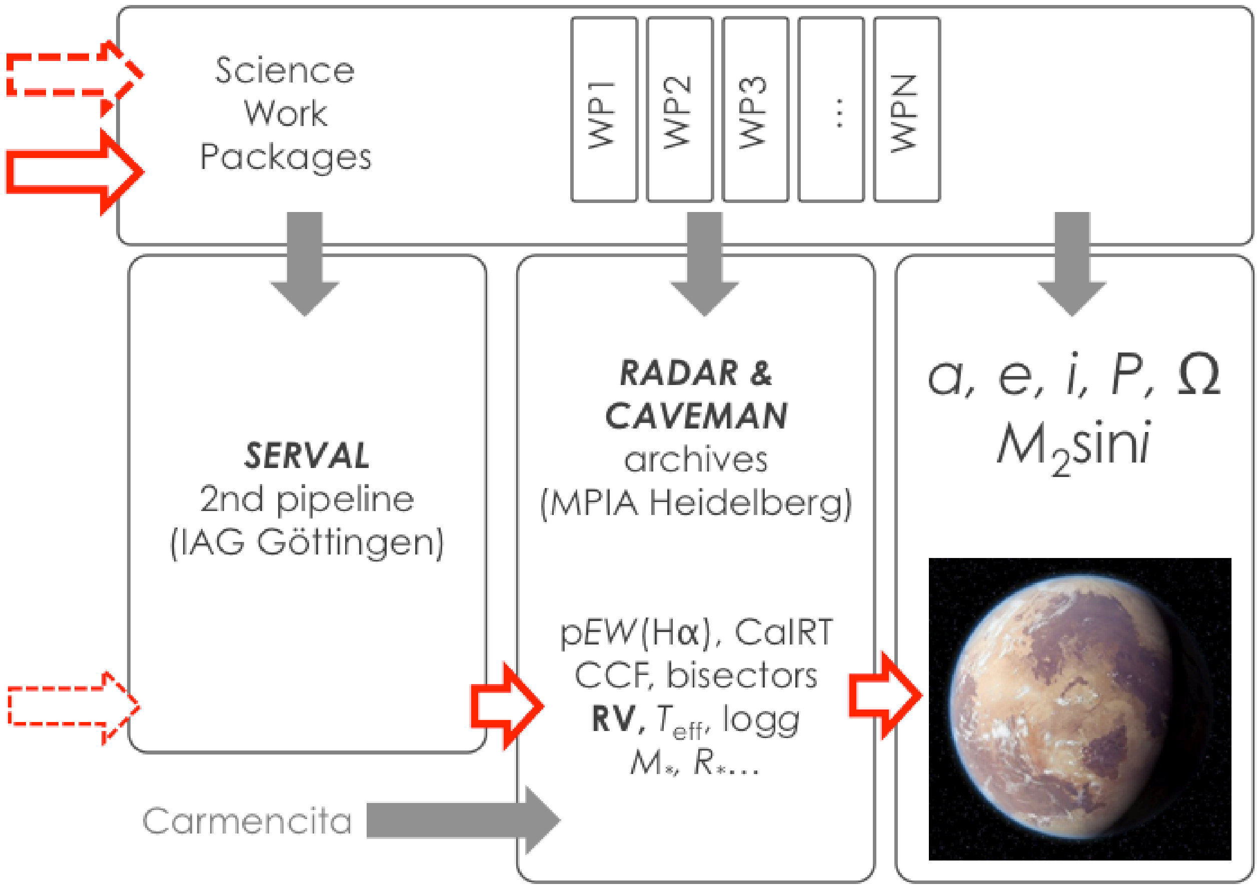

Figure 9: CARMENES data flow. V. Second pipeline, radial-velocity archive, visualisation tool and final planetary system parameters.

The scope of CAVEMAN is threefold. First, it will be used to generate a standard analysis report for every star of the CARMENES survey. Second, it will provide an extendable standard set of data visualisation and analysis tools for the users of the survey data. These python-based tools are very flexible and can be modified by all users according to their needs. Third, CAVEMAN will provide a platform for the joint development and contribution of visualisation and analysis tools by the CARMENES user community. Such contributed tools can in principle become standard tools. This will make it possible to bring the expertise from different groups together, thereby optimising the scientific analysis of every star of the survey.

3. SUMMARY

CARMENES is the first astronomical instrument that delivers spectra covering from 0.5 μm to 1.7 μm with spectral resolution R > 80,000 and long-term stability of ~1 m s^{-1}. Because of that, it is becoming a cornerstone for the search and confirmation of very low-mass exoplanets (mini-neptunes, super-earths and less massive ones) around the coolest and most abundant stars of the Milky Way. For reaching the required stability, the CARMENES data flow is exquisitely tracked, monitored and analysed from the target selection, through the spectra compilation, to the data reduction and archiving.

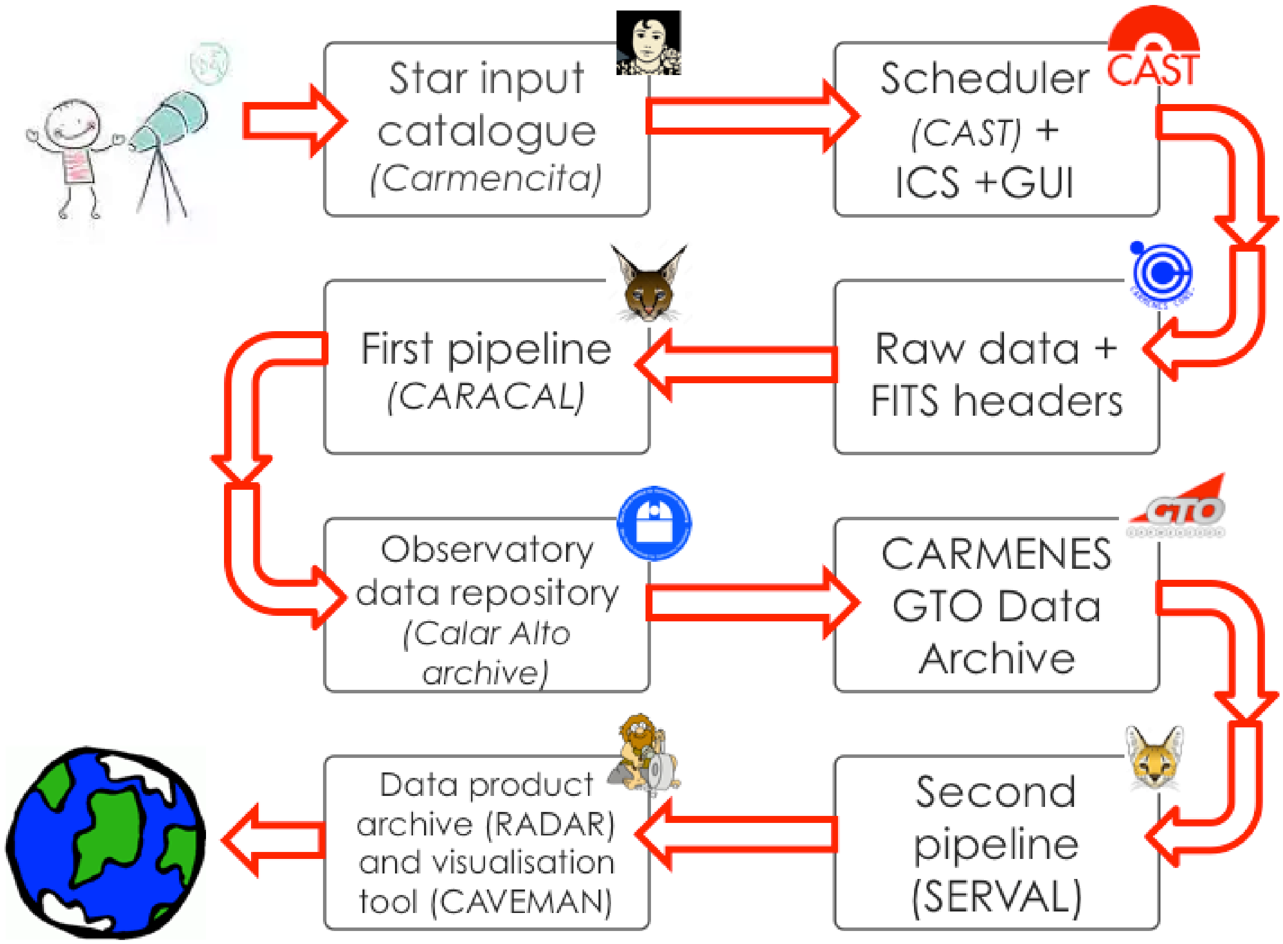

Figure 10: The whole CARMENES data flow from the astronomer to the exoearth.

In this proceeding, we describe in detail all the steps of the CARMENES guaranteed data observations data flow (Fig. 10): (*i*) the CARMENES input catalogue (Carmencita); (*ii*) the scheduler (CAST), instrument control system and graphical user interface; (*iii*) raw data and FITS headers; (*iv*) the spectrum extraction and wavelength-calibration pipeline (CARACAL); (*v*) the observatory data repository and archive; (*vi*) the guaranteed time observations data archive; (*vii*) the radial-velocity pipeline (SERVAL); (*viii*) the data products archive (RADAR) and visualisation tool (CAVEMAN).

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APPENDIX: VIS-CHANNEL FITS HEADER TEMPLATE

```
SIMPLE  =                    T / File conforms to FITS standard
BITPIX  =                   16 / Number of bits per data pixel
NAXIS   =                    2 / Number of data axes
NAXIS1  =                 4250 / Length of data axis 1
NAXIS2  =                 4250 / Length of data axis 2
COMMENT   FITS (Flexible Image Transport System) 2010A&A...524..A42P
EXTEND  =                    T / FITS dataset may contain extensions
BZERO   =                32768 / Data value offset
BSCALE  =                    1 / Data value scale factor
DATAMAX =                      / Maximum data value in array
DATAMIN =                      / Minimum data value in array
FILENAME= ''                   / This file name
OBJECT  = ''                   / Observed object
DATE-OBS= ''                   / UTC at observation start
MJD-OBS =                      / Modified Julian Date at observation start
LST     = ''                   / [h] Local sidereal time
EXPTIME =                      / [s] Exposure time on VIS CCD
RA      =                      / [deg] [hh:mm:ss.ss] Requested right ascension
DEC     =                      / [deg] [+dd:mm:ss.s] Requested declination
RADESYS = 'FK5     '           / Reference frame of equatorial coordinates
EQUINOX = 2000.0               / Equinox of the coordinate system
AIRMASS =                      / Airmass at observation start
PROG-NUM= ''                   / CAHA internal programme number
PROG-PI = ''                   / CAHA internal programme PI identifier
OBSERVER= ''                   / Observer surname or identification
FOLDER  = ''                   / Corresponding night data folder
OBSERVAT= 'CAHA    '           / Centro Astronomico Hispano-Aleman de Calar Alto
TELESCOP= 'CA-3.5  '           / 3.5 m Calar Alto Telescope
INSTRUME= 'CARMENES'           / CARMENES
SUBSYS  = 'vis         '       / Visual channel
REFERENC= '2014SPIE.9147E..1FQ' / Quirrenbach et al. 2014, SPIE, 9147, E1F
ORIGIN  = 'CARMENES'           / http://carmenes.caha.es
COMMENT1= ''                   / Exposure comment
COMMENT2= ''                   / Night comment
HIERARCH CAHA INS SCHEDULER MODE = '' / Scheduler mode (GTO only)
HIERARCH CAHA INS SCHEDULER KARMN = '' / Carmencita name (GTO only)
HIERARCH CAHA INS SCHEDULER RA = '' / Carmencita RA J2000 (GTO only)
HIERARCH CAHA INS SCHEDULER DEC = '' / Carmencita DEC J2000 (GTO only)
HIERARCH CAHA INS SCHEDULER J_MAG = / [mag] J magnitude (GTO only)
HIERARCH CAHA INS SCHEDULER SPTYPE = '' / Spectral type (GTO only)
HIERARCH CAHA INS SCHEDULER NIGHTQUA = '' / Night quality (GTO only)
HIERARCH CAHA INS ICS CATEGORY= '' / Data category
HIERARCH CAHA INS ICS IMAGETYP= '' / Type of observation
HIERARCH CAHA INS ICS FIB-MODE= '' / Fibre observation mode
HIERARCH CAHA INS ICS OBS-MODE= '' / ICS observing mode
HIERARCH CAHA INS ICS OB-NAME = '' / Observing block name
HIERARCH CAHA INS ICS OB-START = '' / UT at start of observing block
HIERARCH CAHA INS ICS NUM-EXP = / Cardinal number of series of exposures
HIERARCH CAHA INS ICS NUM-SEQ = / Ordinal number of a exposure in a series
HIERARCH CAHA INS ICS DATE-AVG= '' / UTC at midpoint of observation (ExpMeter)
HIERARCH CAHA INS ICS VERSION = 'vX.XX' / Released 20160301
HIERARCH CAHA GEN AMBI TEMPERATURE = / [oC] Air temperature
HIERARCH CAHA GEN AMBI DEWPOINT = / [oC] Dew point temperature
HIERARCH CAHA GEN AMBI RHUM = / [%] Relative humidity
HIERARCH CAHA GEN AMBI WIND SPEED = / [m/s] Wind speed
HIERARCH CAHA GEN AMBI WIND GUST = / [m/s] Wind gust
HIERARCH CAHA GEN AMBI WIND DIR = / [deg] Wind dirrection
HIERARCH CAHA GEN AMBI PRESSURE = / [hPa] Air pressure
HIERARCH CAHA GEN AMBI RAIN = / RAIN
HIERARCH CAHA GEN AMBI EXTINCTION = / [mag] Visual extinction in V band
HIERARCH CAHA GEN AMBI SEEING = / [arcsec] Seeing in V band
HIERARCH CAHA TEL POS SET RA = / [deg] [hh:mm:ss.ss] Set telescope right ascension
HIERARCH CAHA TEL POS SET DEC = / [deg] [+dd:mm:ss.s] Set telescope declination
HIERARCH CAHA TEL POS SET EQUINOX = / Set telescope equinox
HIERARCH CAHA TEL POS EL_START = / [deg] Telescope elevation at exposure start
HIERARCH CAHA TEL POS AZ_START = / [deg] Telescope azimuth at exposure start
HIERARCH CAHA TEL POS HA_START = / [deg] Telescope hour angle at exposure start
```

```
HIERARCH CAHA TEL POS DOME_EL_UPP_E = / [deg] Upper segment limit angle
HIERARCH CAHA TEL POS DOME_EL_LOW_E = / [deg] Lower segment limit angle
HIERARCH CAHA TEL POS DOME_AZ = / [deg] Dome azimuth
HIERARCH CAHA TEL FOCU ID = / Cassegrain focus
HIERARCH CAHA TEL FOCU F_RATIO = 3.48 / Focal ratio
HIERARCH CAHA TEL FOCU LEN = 12.195 / [m] Focal length
HIERARCH CAHA TEL FOCU SCALE = 0.169 / [mm/arcsec] Plate scale
HIERARCH CAHA TEL FOCU VALUE = 32.988 / [mm] Absolute telescope focus
HIERARCH CAHA TEL MIRR S1 COLLAREA = 9.09 / [m^2]
HIERARCH CAHA TEL GEOELEV = 2168. / [m] Height above sea level
HIERARCH CAHA TEL GEOLAT = 37.2210917 / [deg] Geographical latitude
HIERARCH CAHA TEL GEOLON = -2.5468333 / [deg] Geographical longitude
HIERARCH CAHA INS FRONTEND PICKMIRR = '' / Pick-up mirror position
HIERARCH CAHA INS FRONTEND ADCANG1 = / [deg] Rot-angle of 1st ADC prism
HIERARCH CAHA INS FRONTEND ADCANG2 = / [deg] Rot-angle of 2nd ADC prism
HIERARCH CAHA INS FRONTEND ADCAUTO = '' / Automatic set of ADC angles
HIERARCH CAHA INS FRONTEND VISCAL = '' / VIS fibre cal-mirror position
HIERARCH CAHA INS FRONTEND NIRCAL = ''/ NIR fibre cal-mirror position
HIERARCH CAHA INS FRONTEND VISSHUTTER = / VIS channel shutter in auto mode
HIERARCH CAHA INS FRONTEND TEMP1 = / [oC] FE temperature near A&G camera
HIERARCH CAHA INS FRONTEND TEMP2 = / [oC] FE temperature near fibre feed
HIERARCH CAHA INS FRONTEND TEMP3 = / [oC] FE temperature near elec-box
HIERARCH CAHA INS FRONTEND HUM1 =  / [%] FE humidity near A&G camera
HIERARCH CAHA INS FRONTEND HUM2 = / [%] FE humidity near fibre feed
HIERARCH CAHA INS FRONTEND GUIDE EXPTIME = / [s] Guiding individual exptime
HIERARCH CAHA INS FRONTEND GUIDE PERIOD = / [s] Guiding period
HIERARCH CAHA INS FRONTEND GUIDE WEIGHT = / Guiding weight
HIERARCH CAHA INS CHAMBER T-ROOM-EAST = / [K] NIR room temperature
HIERARCH CAHA INS CHAMBER T-FLOW-EAST = / [K] NIR flow temperature
HIERARCH CAHA INS CHAMBER T-ROOM-WEST = / [K] VIS room temperature
HIERARCH CAHA INS CHAMBER T-FLOW-WEST = / [K] VIS flow temperature
HIERARCH CAHA INS CHAMBER T-ROOM-CAL = / [K] Calibration room temperature
HIERARCH CAHA INS CHAMBER T-CORRIDOR = / [K] Technical area temperature
HIERARCH CAHA INS VIS MODE = '' / VIS channel mode
HIERARCH CAHA INS VIS FIB-SHAKER = / [mA] VIS fibre shaker current
HIERARCH CAHA INS VIS EXPMETER STATUS = / VIS ExpMeter status
HIERARCH CAHA INS VIS EXPMETER FILE = '' / VIS ExpMeter file
HIERARCH CAHA INS VIS ETALON SHUTTER = '' / F-P shutter status in CalUnit
HIERARCH CAHA INS VIS ETALON UT-OPEN = / UTC at F-P shutter opening
HIERARCH CAHA INS VIS ETALON UT-CLOSE = / UTC at F-P shutter closing
HIERARCH CAHA INS VIS ETALON CURRENT = / [A] F-P halogen lamp current
HIERARCH CAHA INS VIS ETALON VOLTAGE = / [V] F-P halogen lamp voltage
HIERARCH CAHA INS VIS ETALON P-VALVE = / [hPA] Pressure F-P valve (VIS-FP-S1)
HIERARCH CAHA INS VIS ETALON P-COMMON = / [hPA] Pressure common NIR/VIS valve (NIR-VIS-FP-S2)
HIERARCH CAHA INS VIS ETALON T-THERMO = / [oC] Internal temperature of thermopump
HIERARCH CAHA INS VIS CALUNIT OCTAGON = / Octagon lamp mirror position
HIERARCH CAHA INS VIS CALUNIT LAMP = / Corresponding lamp
HIERARCH CAHA INS VIS CALUNIT LAMP-OK = / Light coming from octagon
HIERARCH CAHA INS VIS CALUNIT FILTER SCIENCE = '' / 'A' wheel filter
HIERARCH CAHA INS VIS CALUNIT FILTER CALIBRA = '' / 'B' wheel filter
HIERARCH CAHA INS VIS CALUNIT SOCKET NUM1 = / (UN0) 0th U-Ne lamp status
HIERARCH CAHA INS VIS CALUNIT SOCKET NUM2 = / (UA1) 1st U-Ar lamp status
HIERARCH CAHA INS VIS CALUNIT SOCKET NUM3 = / (UN1) 1st U-Ne lamp status
HIERARCH CAHA INS VIS CALUNIT SOCKET NUM4 = / (TN1) 1st Th-Ne lamp status
HIERARCH CAHA INS VIS CALUNIT SOCKET NUM5 = / (UA2) 2nd U-Ar lamp status
HIERARCH CAHA INS VIS CALUNIT SOCKET NUM6 = / (UN2) 2nd U-Ne lamp status
HIERARCH CAHA INS VIS CALUNIT SOCKET NUM7 = / (TN2) 2nd Th-Ne lamp status
HIERARCH CAHA INS VIS CALUNIT SOCKET HALOGEN = '' / Flat-field hal lamp status
HIERARCH CAHA INS VIS CALUNIT SOCKET CURRENT1 = / [mA] Current of UN0
HIERARCH CAHA INS VIS CALUNIT SOCKET CURRENT2 = / [mA] Current of UA1
HIERARCH CAHA INS VIS CALUNIT SOCKET CURRENT3 = / [mA] Current of UN1
HIERARCH CAHA INS VIS CALUNIT SOCKET CURRENT4 = / [mA] Current of TN1
HIERARCH CAHA INS VIS CALUNIT SOCKET CURRENT5 = / [mA] Current of UA2
HIERARCH CAHA INS VIS CALUNIT SOCKET CURRENT6 = / [mA] Current of UN2
HIERARCH CAHA INS VIS CALUNIT SOCKET CURRENT7 = / [mA] Current of TN2
HIERARCH CAHA INS VIS CALUNIT SOCKET AGE1 = / [mA h] Age of UN0
HIERARCH CAHA INS VIS CALUNIT SOCKET AGE2 = / [mA h] Age of UA1
HIERARCH CAHA INS VIS CALUNIT SOCKET AGE3 = / [mA h] Age of UN1
HIERARCH CAHA INS VIS CALUNIT SOCKET AGE4 = / [mA h] Age of TN1
HIERARCH CAHA INS VIS CALUNIT SOCKET AGE5 = / [mA h] Age of UA2
HIERARCH CAHA INS VIS CALUNIT SOCKET AGE6 = / [mA h] Age of UN2
HIERARCH CAHA INS VIS CALUNIT SOCKET AGE7 = / [mA h] Age of TN2
HIERARCH CAHA INS VIS CALUNIT SOCKET LAMPNUM1 = / ID of UN0
HIERARCH CAHA INS VIS CALUNIT SOCKET LAMPNUM2 = / ID of UA1
HIERARCH CAHA INS VIS CALUNIT SOCKET LAMPNUM3 = / ID of UN1
HIERARCH CAHA INS VIS CALUNIT SOCKET LAMPNUM4 = / ID of TN1
HIERARCH CAHA INS VIS CALUNIT SOCKET LAMPNUM5 = / ID of UA2
HIERARCH CAHA INS VIS CALUNIT SOCKET LAMPNUM6 = / ID of UN2
```

```
HIERARCH CAHA INS VIS CALUNIT SOCKET LAMPNUM7 = / ID of TN2
HIERARCH CAHA INS TANK P-INSIDE = / [hPa] P inside VIS vacuum tank (VT-S1)
HIERARCH CAHA INS TANK P-PUMPS = / [hPa] P VIS VT rough/turbo pumps (VT-S2)
HIERARCH CAHA INS TANK P-SORPTION = / [hPa] (VT-S3) P VIS VT sorption pump (VT-S3)
HIERARCH CAHA INS TANK T-SORPTION = / [K] T VIS VT sorption pump (SP-Temp)
HIERARCH CAHA INS TANK T-OB1 = / [K] OB T near coll mirr, det side (IS-TS1)
HIERARCH CAHA INS TANK T-OB2 = / [K] OB T near coll mirr, ech side (IS-TS2)
HIERARCH CAHA INS TANK T-OB3 = / [K] OB T near ExpMeter FIU (IS-TS3)
HIERARCH CAHA INS TANK T-OB4 = / [K] OB T near grism mount (IS-TS4)
HIERARCH CAHA INS TANK T-OB5 = / [K] OB T echelle, lo side (IS-TS5)
HIERARCH CAHA INS TANK T-OB6 = / [K] OB T near near FEU (IS-TS6)
HIERARCH CAHA INS TANK T-OB7 = / [K] OB T near camera (IS-TS7)
HIERARCH CAHA INS TANK T-OB8 = / [K] OB T echelle, hi side (IS-TS8)
HIERARCH CAHA INS CRYO P-INSIDE = / [hPa] P inside VIS cryostat (CR-S1)
HIERARCH CAHA INS CRYO P-PUMP = / [hPa] P VIS cryostat pump (CR-S2)
HIERARCH CAHA INS CRYO T-BASE = / [K] T VIS detector head base (CR-TS1)
HIERARCH CAHA INS CRYO T-HOUSING = / [K] T VIS detector head housing (CR-TS2)
HIERARCH CAHA INS CRYO T-FINGER = / [K] T VIS cryostat cooling finger (CR-TS3)
HIERARCH CAHA INS CRYO T-EXHAUST = / [K] T VIS cryostat gas exhuast (CR-TS4)
HIERARCH CAHA INS CRYO T-SORPTION = / [K] T VIS cryostat sorption pump (CR-TS5)
HIERARCH CAHA INS CRYO HT-BASE =/ [%] Heater ratio of det-head base (CR-HT01)
HIERARCH CAHA INS CRYO HT-HOUSING =/ [%] Heater ratio of det-head housing (CR-HT02)
HIERARCH CAHA INS CRYO VALVE-EXHAUST = '' / Gas exhaust valve status (CR-HT03)
HIERARCH CAHA INS CRYO HT-EXHAUST = '' / Gas exhaust heater status (CR-HT04)
HIERARCH CAHA INS CRYO HT-SORPTION = '' / Sorption pump heater status (CR-HT05)
HIERARCH CAHA INS CRYO P-BOTTLE = / [bar] P VIS cryostat LN2 bottle syphon (CR-S3)
HIERARCH CAHA INS CRYO LN2LEVEL = / [%] VIS cryostat LN2 bottle level (CR-DW)
HIERARCH CAHA INS VIS CCD DETECTOR = 'e2v CCD231-84' / VIS e2v CCD
HIERARCH CAHA INS VIS CCD UT = / [s] UTC Unix at observation start
HIERARCH CAHA INS VIS CCD RO_SPEED = '' / CCD read-out speed
HIERARCH CAHA INS VIS CCD TIM_FILE = '' / CCD timing file
END
```