

# 1 The Gaia-ESO Survey

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The Gaia-ESO Survey is a public spectroscopic survey, targeting  $\geq 10^5$  stars, systematically covering all the major components of the Milky Way, from halo to star forming regions, providing the first homogeneous overview of the distributions of kinematics and elemental abundances. This alone will revolutionise knowledge of Galactic and stellar evolution: when combined with Gaia astrometry, the Survey will quantify the formation history and evolution of young, mature and ancient Galactic populations. With well-defined samples, based primarily on ESO-VISTA photometry for the field stars, and by a variety of photometric surveys of open clusters, the Survey will quantify the kinematic-multi-element abundance distribution functions of the bulge, the thick and the thin discs and the halo stellar components, as well as a significant sample of  $\sim 100$  open star clusters, covering all accessible cluster ages and stellar masses.

FLAMES spectra will: quantify individual elemental abundances; yield precise radial velocities for a 4-D kinematic phase-space; map kinematic gradients and abundance - phase-space structure throughout the Galaxy; and follow the formation, evolution and dissolution of open clusters as they populate the disc. Several GIRAFFE settings, optimised for the astrophysical parameters of each target group, and parallel UVES spectra will be obtained for each surveyed open cluster. GIRAFFE spectra, with two settings, will be obtained for statistically significant samples of stars in all major stellar populations. These will be supplemented by UVES spectra of an unbiased sample of G-stars within  $\geq 1$  Kpc of the Sun, providing the abundance distribution function for the local thin disc, thick disc and halo. The open cluster survey targets contribute to testing stellar evolution models from pre-main sequence phases right through to advanced evolutionary stages, and provide a legacy dataset that adds enormous value to the Gaia mission and ongoing ESO imaging surveys.

The Gaia-ESO Survey delivers the data to support a wide variety of studies of stellar populations, the evolution of dynamical systems, and stellar evolution. Gaia-ESO complements Gaia by using UVES to measure the metallicity and detailed abundances for several chemical elements in  $\sim 5000$  field stars with  $V \leq 15$  and in  $\sim 2000$  open cluster members down to  $V \sim 16.5$ . Depending on target signal-to-noise ratio (SNR), and astrophysical parameters, the Survey typically probes the two fundamental nucleosynthetic channels, nuclear statistical equilibrium (V, Cr, Mn, Fe, Co), and  $\alpha$ -chain (Si, Ca, Ti).  $[\text{Fe}/\text{H}]$ ,  $[\alpha/\text{Fe}]$ , and possibly other element abundance ratios will be obtained from GIRAFFE spectra. The radial velocity (RV) precision for this sample will be  $\simeq 0.1 \text{ km s}^{-1}$  to  $\leq 5 \text{ km s}^{-1}$ , depending on target, with in each case the measurement precision being that required for the relevant astrophysical analysis. Appropriate precision in RV determination for low-mass cluster members is critical to test models of cluster formation, evolution, and dissolution, which is one of the key goals of the Survey.

The Gaia-ESO dataset will identify, on both chemical and kinematic grounds, phase-space substructures that bear witness to specific merger or starburst events. The dataset will also allow following the dissolution of clusters, and the Galactic migration of field stars. The Survey not only supplies homogeneously determined element abundances, but also stellar rotation rates, and diagnostics of magnetic activity and accretion, for large samples of members of clusters with future precise distances from Gaia. This information can be used to challenge models of stellar structure and evolution, as well as to test models of mass accretion from circumstellar discs into the star.

The Gaia-ESO Survey will invest considerable effort in archive re-analyses, and in abundance calibration, establishing a “standard grid” appropriate for use by other spectroscopic surveys, to ensure maximal legacy value.

The Gaia-ESO Survey wiki for private team use is <http://great.ast.cam.ac.uk/GESwiki/GESHome>.

The Survey will provide a public archive on public data release, and a public web site, <http://www.gaia-eso.eu>, in 2012

## 2 Survey Observing Strategy

The Gaia-ESO Survey observing strategy has been designed to deliver the top-level Survey goals. The Survey includes the Galactic inner and outer bulge, inner and outer thick and thin discs, the halo and known halo streams. There is special focus on open clusters at all ages, and on solar neighbourhood field stars, as these trace both stellar and Galactic evolution, complement Gaia astrometry, and will benefit most from the most precise Gaia data.

Observations are restricted to  $+10^\circ \geq \text{DEC} \geq -60^\circ$  whenever possible to minimise airmass limits. The primary source catalog for field stars is VISTA imaging, ensuring excellent recent astrometry, and adding maximal value to the VISTA surveys. The open clusters have mostly been selected from the Dias et al. (2002, A&A 389, 871 -2010 version) and Kharchenko et al. (2005, A&A 440, 403) catalogues, and the WEBDA database [<http://www.univie.ac.at/webda>]. Only clusters with excellent available photometry and astrometry, and adequate membership information, have been selected.

**Bulge Survey.** Here the prime targets are K giants, including the red clump ( $I = 15$  typically). These dominate the relevant CMD selection. Two GIRAFFE settings are needed (HR21, HR10), implying up to 4H/fibre setup, depending on the field and the extinction. This will measure Mg, Ca, Ti for most stars, and Si, Cr, Mn, and Ni for many stars. The bulge RGB is clearly visible in CMDs at  $b \leq 45^\circ$ , so this survey will extend that far. In low extinction regions, brighter gK stars will be observed with UVES 580-nm parallels to sample both bulge and inner Galaxy populations.

**Halo/thick disc Survey.** Primary targets are  $r=17-18$  F+G stars, with the bluer, fainter F stars probing the halo, brighter, redder F/G stars probing the thick disc. SDSS analyses show a clear thick disc/halo transition in the range  $17 \leq r \leq 18$  – Gaia-ESO uses the equivalent selection from VISTA. The spectra will allow measurement of both iron-peak elements and alpha elements, for stars down to  $[M/H] \leq -1.0$ . In fields crossing known halo streams (eg Sgr), stream K giant candidates will be observed. A subset of fibres will be allocated to specially selected candidate members of rare but astrophysically important stellar populations, such as extremely metal poor stars. The fields are distributed in the whole sky, but predominately in the Galactic cap (SGC, NGC) regions. This minimises scheduling clashes with the cluster targets, and ensures southern and northern fields for scheduling, and photometric overlap with SDSS, PS1, and ESO/VST.

**Outer thick disc, 2-4 kpc from the Sun.** Fields will have distant F/G stars as prime targets, and 2 settings, as for the halo in both requirements and measurables. This well-defined low latitude sample probes 2-4 kpc, more than a radial scale length. In addition, 25% of the fibres are allocated to candidate K giants ( $r \leq 18$ ), which probe the far outer disc, warp, flare and Monoceros stream.

**Thin disc dynamics.** Up to 6 fields will be observed with candidate red clump stars to  $I \leq 19$  in the Galactic Plane to test spiral arm/bar dynamics. These require HR21 for radial velocities (RVs) only. Several thousand RVs per line of sight will be obtained.

**Solar Neighbourhood.** UVES parallels for the field surveys are dedicated to an unbiased sample of order 5000 G-stars extending  $\geq 1$  kpc from the Sun, to quantify the local detailed elemental abundance distribution functions. The sample is photometrically-selected to ensure all possible ages and metallicities for unevolved stars and subgiants are sampled. UVES 580-nm setting is adopted. These are parallel observations, requiring no dedicated time.

**Open clusters –OCs.** Cluster selection is optimised to fine-sample age-[Fe/H]-Galactocentric distance-mass parameter space. OCs in all phases of evolution (except embedded), with ages from  $\sim 10^6$  yr to  $\sim 10$  Gyr will be included, sampling different environments and star formation conditions. This provides sufficient statistics to explore the dynamical evolution of clusters. The same sample maps stellar evolution as a function of metallicity for  $0.1 \leq M/M_\odot \leq 100$ , including short-lived evolutionary phases, and quantifies the distribution of metallicity as a function of Galactocentric radius and time. The total sample includes  $\sim 100$  clusters. The young cluster ( $<100$  Myr) sample includes: *i*) targets closer than  $\sim 1500$  pc, the distance up to which Gaia will provide transverse velocity with precision better than internal velocity dispersion, matched with equally precise Survey RVs; *ii*) clusters at larger distances, where OBA stars will be targeted. The older cluster sample includes both nearby and distant clusters. In nearby clusters the Survey covers the whole population, down to the M dwarf regime, while in the most distant ones RGB and clump giants, and earlier-type main sequence and turn-off stars, are targeted. The cluster sample covers the Galactocentric distance range from about 6 up to

$\sim 20$  kpc. For all clusters GIRAFFE targets faint cluster members (down to  $I = 19$ ), while UVES observes brighter and key objects (down to  $V = 16.5$ ), to be used for accurate abundance determination or for which better precision in RV is required. Seven GIRAFFE set-ups will be employed (HR03/05A/06/10/14A/15N/21). HR03/05A/06/10/14A contain a large number of spectral features to be used to derive RVs and characteristics (e.g., temperature, gravity, wind) of early-type stars; HR15N/21 are the most commonly used gratings for late-type stars; they access a large enough number of lines to derive RVs, as well as to retrieve key information on the star characteristics (e.g., temperature, Li, accretion rates, chromospheric activity, rotation). UVES CD3 is most suitable both for early-type (520-nm setting) and late-type (580-nm setting) stars. The number of FPOSS configurations for each cluster will depend on both the number of cluster candidates and the cluster extension in the sky. Total number of 1hr OBs for each FPOSS configuration and set-up will depend on both the magnitude distribution and SNR requirements for that particular subset of stars. Multiple exposures of the same FPOSS configurations for the clusters will also allow the identification of binaries. The RA distribution of the clusters is described below.

**Calibration Fields** Gaia-ESO dedicates considerable effort to define calibration stars - clusters, special fields, CoRoT fields, stars which are Gaia calibrators, etc, to ensure Gaia-ESO is optimally calibrated, and that other major surveys can be calibrated onto compatible parameter scales. Twilight observations will be used as much as possible.

**Archive data** The Survey team has analysed the ESO archive for abundance calibrations, and complementary data. The on-going [AMBRE] re-analysis of the ESO archive is being done consistently with the Gaia-ESO Survey, to ensure maximum value. All relevant archive data are to be analysed as part of this Survey, to ensure maximum consistency across all datasets. Open cluster selection is based on a critical analysis of available data in the archive, in order not to re-observe cluster members for which spectra with the required set-up and SNR are already available. Calibration targets have been selected to optimise the archive value, by allowing available spectra to be re-calibrated onto our abundance system.

**Input catalogue availability** The Gaia-ESO Survey input and target selection catalogues are primarily VISTA, for the field survey, and 2MASS and/or ESO-WFI for clusters. These are precise, proven catalogues, ensuring astrometric and photometric input data are of uniform and optimal quality. Vista has sufficient sky coverage at the start of the Gaia-ESO Survey to meet the full science goals of the Survey. While continuing Vista data will enhance the Gaia-ESO Survey target selection options, no imaging data are essential which are not available.

## 2.1 Observing mode

Observations for the Gaia-ESO Survey will be executed in visitor mode. The Survey team will prepare and check in the observing blocks (OBs) at Paranal via the local P2PP and ESO Observing Tool (OT). The Survey team will ensure that a sufficient number of OBs is available for each observing run, covering as wide a range of target positions and match to observing conditions as is consistent with the Survey scientific requirements, to allow optimal use of actual weather conditions.

The Co-PIs will, in agreement with ESO, identify a small team of observers ( $\sim 7$  at any time), including (some of) the present ESO staff and Fellows who are scientific members of the Gaia-ESO Survey, scientists who have been ESO Fellows, and other team members as required. This will ensure availability of experienced observers, who are familiar with Survey requirements and progress, and are able to make optimal real-time decisions. The observing team forms WG 0.

There will be one experienced visiting observer at Paranal. Working Group leads or relevant Working Group members who are affected by the observing priority, and contribute to optimisation, should be present for at least one observing run, to understand real constraints. This visit will correspond to times when a local Paranal Fellow is the second VA, so ESO never funds more than one international trip. Thus we average 6 runs/year with 2 observers, 6 runs with one.

The observing team and the Co-PIs, with the relevant WGs (cf below) will develop a clearly documented set of observing instructions, and a clear set of current observing priorities, with updates each semester.

Table 1: Scheduling requirements

Period	OPC nights	runs	run length (N)
P88	15	3	5
P89	30	6	5
P90	30	6	5
P91	30	6	5
P92	30	6	5
P93	30	6	5
P94	30	6	5
P95	30	6	5
P96	15	3	5
<b>Review point to assess Y5 ops and compensation time</b>			
P96	tbc	tbc	tbc
P97	tbc	tbc	tbc
P98	tbc	tbc	tbc

**ToO policy:** ESO OPC allocates a number of Target of Opportunity (ToO) and Rapid Response Mode ToO (RRM/ToO) triggers which may be accepted as overrides by a Visiting Observer, with time replacement at the discretion of the Paranal Director. To maximise the science output of Paranal, the Gaia-ESO Survey will accept ToO and RRM/ToO overrides recommended by the Paranal Director, and make available the VLT for their observation.

In order to optimise efficiency, and especially for brighter calibration targets, observations will always extend into nominal twilight in so far as telescope operations and observing conditions permit.

All relevant observing and calibration data will be available to the Co-PIs through archive download, with calselector for the associated calibration files, within 2 days after each observing run.

## 2.2 Scheduling requirements

The distribution of targets in the Gaia-ESO Survey is, by design, sufficiently well spread that uniform scheduling is possible. The bias in the open cluster distribution to the Galactic Plane, and especially the outer Galaxy, is naturally complementary to the field Survey bias to higher Galactic latitudes and the bulge. The relative paucity of cluster targets in the RA range 16H-0H is compensated by the larger number of priority field targets in the RA range 16H-20H, including the Galactic bulge and inner disc; the opposite holds for the RA range 5H-10H. The scheduling requirements will be reviewed periodically, and updated as survey progress requires. Priorities will be refined semester by semester based on the results of previous runs.

A list of science open cluster targets for each semester will be provided to ESO by February 1 and August 1 of each year, in advance of the relevant ESO Call for Proposals, so that the target list can be available at the Call.

Table 1 summarizes the overall schedule for the 240N allocated by the OPC to the Survey for the first four years. Replacement time for poor conditions and weather or technical downtime is considered at a Year 4 review, as is continuation of the Survey for year 5. The algorithm we will apply to propose for replacement time is described below (Sect. 2.4).

In Table 2 we summarize the RA distribution and observing semesters for the different target categories, along with information on the GIRAFFE and UVES set ups; Table 3 lists the requested number of nights as a function of RA.

Table 2: Observing requirements: summary by science category

Target	lines of sight	nights	RA range	UVES setups	Giraffe setups
Bulge	150	55	15H - 21H	580nm	HR10, HR21
Thick Disc	40	15	5H - 10H	580nm	HR10, HR21
Thin Disc	10	10	7H - 19H	580nm	HR21
Halo-SGC	170	60	20H - 6H	580nm	HR10, HR21
Halo-NGC	80	25	10H - 15H	580nm	HR10, HR21
Calibrations	40	10*	0H - 24H	580nm	HR10, HR14A, HR15N, HR21
Young Clusters (ctd)	30**	64	0H-11H, 16H-18H	520nm, 580nm	HR03, HR05A, HR06, HR14A, HR15N, HR21
Int age & old Clusters	65**	61	5H-19H	520nm, 580nm	HR15N, HR21

\* plus twilights when available; \*\* number of clusters

Table 3: Observing requirements: summary by RA range

Targets	0H-5H	5H-10H	10H-15H	15H-20H	20H-0H
Field	32n	19n	29n	47n	38n
Clusters	22n	62n	12n	29n	–
Calibrators	2n	2n	2n	2n	2n

### 2.3 Observing conditions requirements

The science requirements - range and accuracy of elemental abundances, RV accuracy - directly define the observing requirements. Given the large variety of objects (spectral-type, colors, metallicity, etc) these cover a wide range of values.

**Open Clusters** For the observation of stars in intermediate-age and old open clusters, the targets to be observed with the UVES fibres dictate the exposure time, with typical SNR  $\geq 60$  per pixel required. In younger clusters UVES fibres will be allocated to pre-main sequence or zero age main sequence G and K-type cluster members, while GIRAFFE fibres will target K and M-type cluster members. Exposure times will be dictated by GIRAFFE, aiming for SNR  $\sim 10$  when only RVs are of interest and for SNR  $\geq 30$  for targets for which additional information will be retrieved from the spectra. Corresponding SNR per pixel for UVES spectra of significantly brighter stars will be greater than  $\sim 80$ . In young distant clusters, O-type stars will be observed with UVES, while fainter B and A-type stars will be observed with GIRAFFE. Exposure times will be driven by the latter. Our tests indicate that for these hot stars a SNR of about 100 or greater is required.

**Field Star Survey** For the field survey GIRAFFE spectra are primary. Extensive analysis tests show that a SNR between  $\sim 30$  and 50 is required, depending on the type of star (e.g., bulge gK candidates vs. fainter FG thick disc and halo stars) and setup (i.e, number of available spectral lines). UVES is operated in parallel, with target stars chosen with magnitudes such that UVES will deliver a goal SNR of 50 on field G stars. For the Galactic Plane fields only RVs are required, so SNR=10 is the goal.

Estimates of the optimal combination of exposure times and observing conditions which would fulfill these Survey science requirements –specifically the goal SNR for the different targets and for the required number of stars– have been performed using GIRAFFE and UVES/FLAMES exposure time calculators (Versions 3.2.7a and 3.2.12, respectively). We have assumed bright sky and airmass equal to 1.2. The results convolved with the target magnitude distribution indicate that  $\sim 70\%$  of time be no worse than CLR sky and 0.8 arcsec seeing.

30% of the time can be CLR sky and no worse than 1.2 arcsec seeing conditions. These observing constraints are those necessary to achieve the required precision to the Survey limit.

We do not request any lunar constraints, but will ensure no observations are attempted within 30° of the moon.

Observations in Visiting Astronomer mode have been required as a condition by ESO. This inevitably implies observations in seeing and weather conditions which are worse than those required for efficient Survey progress. In marginal conditions the Survey will target, where feasible, brighter and calibration targets. In very poor conditions the observer will decide, in agreement with the local responsible ESO staff member, if the telescope should be handed back to ESO. We emphasise that conditions much worse than those used to justify the Survey time allocation are the reason to apply for time compensation.

## 2.4 Survey observing progress/replacement observing time

The Co-PIs will provide a Gaia-ESO Survey progress report to the OPC each semester.

There will be two other regular *Spectroscopic Public Survey* reports to ESO, SPS-obs and SPS-snr. After each observing run a visitor run report (SPS-obs) will be delivered to the ESO Survey Team (EST), providing general run information, the list of OBs for which data was obtained, and noting the distribution of the scheduled time in categories including apparently suitable, marginal, unsuitable, and technical or weather downtime. A more extensive Survey logfile of each run will be kept and archived, explaining all real-time conditions and decisions. A second report (SPS-snr) will provide quantitative progress reporting on actual survey observing conditions, per run and cumulative. The reports SPS-snr will be provided to ESO each semester.

Given the excellent astrometry of the Survey input catalogues, achieved SNR is then a function of actual observing conditions. The delivered SNR can be evaluated for a spectrum only following appropriate processing. Hence, following data delivery from ESO, and pipeline reduction, the Survey data reduction pipelines will generate the distribution of achieved SNR for all spectra, for both GIRAFFE and UVES, and for the different settings. This will quantify delivered SNR for a 1hr OB, as a function of magnitude and spectral-type, when conditions meet the specified 0.8/1.2 arcsec CLR requirements. Comparison of the achieved distribution of SNR in each run with that achieved during actual 0.8/1.2 arcsec CLR conditions quantifies the equivalent amount of observing time in acceptable conditions actually delivered at the telescope during each observing run. The amount of replacement observing time required to achieve the required SNR for targets (partially) observed in relatively poor conditions will also be calculated. It is this quantitative information which will be contained in the SPS-snr reports.

The difference between the equivalent acceptable-quality time and the scheduled time, plus any time lost to unobservable weather and technical downtime, will represent the amount of time applied for at the Year 4 review as compensation. The schedule for time compensation in the fifth year of the Survey will be agreed during the Survey review planned in P94.

Two progress reviews will be held, after 2 years (ie during P92) and during the 4th year (*cf* Sect 8). The second review will be early enough to ensure timely optimisation of the remaining Survey allocation. Each review will compare actual Gaia-ESO Survey progress with this SMP.

## 3 Survey data calibration needs

**Instrumental calibration.** The standard ESO daytime calibrations are assumed, and are required. No other special instrumental calibrations are needed. To meet velocity precision requirements, some (blue) target OBs will include a short arc exposure as part of the normal observing block.

**Astrophysical calibration.** Ensuring the Gaia-ESO Survey has maximal legacy impact is of key priority. Analysis of the literature, the ESO archive, and other projects, has identified a set of open and globular clusters, a set of field stars, including Gaia calibrators and CoRoT targets, which will cross-calibrate all major data sets uniformly, including Gaia, APOGEE, RAVE and HERMES. Together with these other surveys, the

Gaia-ESO Survey will establish a set of key (e.g., equatorial) calibration fields, accessible to all survey projects. Some rare stellar types will also be observed. Calibration clusters will be observed with the same GIRAFFE setups used for field stars, largely in twilight should time be available. Hot and fast rotating stars are ideal standards for removal of telluric absorption features. Calibration is an important task, with 100H assigned, plus twilight use on every night when time is available. Some of the available twilight calibration time will be devoted to observations of RV standards.

## 4 Data reduction process

### 4.1 Project organization

An overview of the Gaia-ESO Survey data flow process is presented in Figure 1. The tasks are distributed among 19 Working Groups (WGs), WG0 to WG18, each of which has a WG coordinator, and membership, who have confirmed their available FTE contribution of effort for a real contribution. The tasks of the WGs are to implement the data flow, from target selection and characterization, through OB preparation, operations and observing, pipeline data processing, detailed spectrum analysis, astrophysical parameter quality/sanity checking and homogenization, to science quality control, through to preparation, documentation and delivery of external data products to both ESO and a dedicated public archive. A 20th WG, dedicated to communication with the general community, is included in the Gaia-ESO Survey project organization.

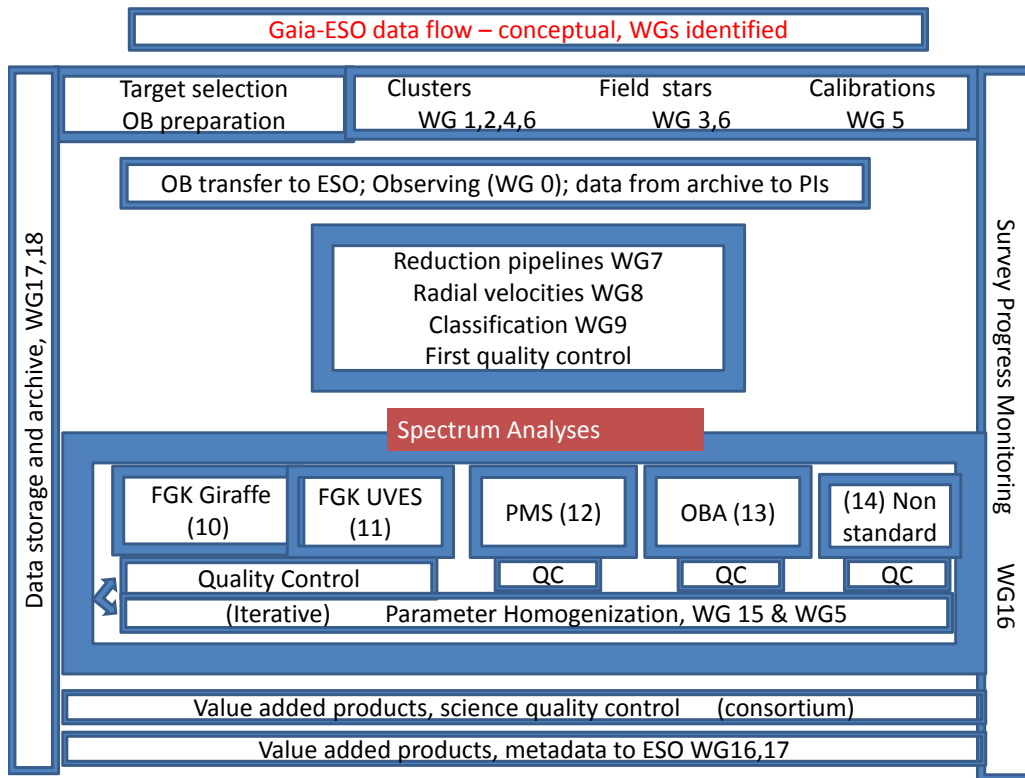


Figure 1: An overview of the Gaia-ESO Survey data flow system.

## 4.2 Target identification, FPOSS and OB preparation (WG1,2,3,4,5,6)

Field star targets will be identified predominately from VISTA CMDs. This will be mostly VHS, with some VVV in the inner Galaxy, supplemented with SDSS, VST as available, and our access to the ongoing PS1, DES and SkyMapper surveys. VISTA data are processed and available at IoA Cambridge. [The VISTA VHS and VVV PIs are part of this project.] To ensure a stable selection function, selected potential target lists will be generated at the Cambridge CASU centre, using VISTA astrometry. At low latitudes in the Galactic Plane special fields are selected, using available photometric data from microlensing surveys, 2MASS, DENIS, and CoRoT.

A master list of science open cluster targets has been defined. Considerable dedicated effort focuses on optimal selection of open cluster target stars, using both model input and the best available detailed astrometric, multi-wavelength photometric and supplementary (e.g., X-ray) information. These activities are coordinated by three WGs, which work in close collaboration between themselves, and with the FPOSS (fibre positioning) and OB preparation WG. Information for all the sample clusters is collected from one of the three WGs; the information is then processed by the membership analysis WG, and then passed to the selection WG, where cluster candidate stars to be observed with UVES and GIRAFFE are finally selected. A catalog listing all these candidates, along with priorities, will be prepared and will provide input for the preparation of the fibre configurations. To this aim 2MASS astrometry has been proven adequate in previous FLAMES observations, and will be used by preference.

Calibration (open and globular cluster) targets are identified and will be observed, to higher than mean SNR. For several of these clusters we will exploit available WFI photometry obtained in the context of the pre-FLAMES survey.

Several groups are able to support FPOSS fibre allocation and OB generation, based on these target algorithms and data files, spreading this workload viably. The two WG coordinators will ensure that, although distributed, FPOSS and OB preparation is performed in a consistent way, and they will provide sanity and consistency checking.

## 4.3 Pipeline processing of raw data from ESO and spectrum extraction(WG7)

Raw data reduction will be performed at CASU/Cambridge (GIRAFFE spectra) and Arcetri (UVES spectra), with all raw data and extracted spectra then being stored centrally at Cambridge. We deliberately process data by spectrograph type rather than by science target at this stage, to ensure field and clusters are treated similarly. The instrument-specific reduction pipelines are to be the current ESO systems. Private special-purpose pipelines capable of processing GIRAFFE data are also available. We will utilise these to investigate possible improvements to extant pipelines. Should Survey experience identify possible enhancements relative to the ESO pipeline, the Co-PIs will communicate with ESO through the forum for science data products to ensure any such algorithms are made available to ESO.

The data reduction pipelines described below are in operation, and have been tested with FLAMES data.

### 4.3.1 UVES

Reduction of UVES data will be performed using the latest public version of the ESO reduction pipeline, running under CPL. The reduction will be performed in a semi-automatic way, following a reduction *cascade*; relevant raw data, including both calibration and science frames, will be selected and inserted into the reduction path. All acquired data will be pipeline-reduced using the best possible master calibration products, which will be produced starting from the best available day-time calibration frames. After quality checks (Sect 6) these will be applied to the reduction of science data. The standard reduction steps will be followed, namely:

- bias and the interorder background are subtracted
- flat-fielded



- every order of the spectrum is extracted Both the optimum and average extraction modes will be used, the extracted spectrum with the highest quality will then be chosen;
- de-convolved for fibre cross talk
- wavelength calibrated
- and corrected for differences in fibre transparency
- the orders are merged
- the sky spectrum from the fibre allocated to the sky will be subtracted from the target spectra; this step will be performed both on the individual orders, and on the merged spectra. Individual orders will be kept and passed to the analysis WGs
- once all the spectra of a given target have been acquired, the individual integrations will be combined into co-added spectra, after measuring the RV, checking for binarity, and velocity shifting to the barycentric frame. Co-added spectra are used to reject cosmic rays from individual spectra

#### 4.3.2 GIRAFFE

Reduction of GIRAFFE spectra will involve the following steps:

- Default basic processing using the ESO pipeline (bias subtraction; cross-talk, scattered light removal; bad pixel masking; flatfielding; wavelength calibration; extraction)
- Wavelength recalibration of each extracted spectrum using sky emission lines, for red wavelength settings, or almost-simultaneous short SIMCAL observations for the bluer settings
- Combining sky fibres for the determination of the master sky spectrum for each integration and subtracting (master or local, as scientifically appropriate) from individual extracted objects
- Combining the individual integrations into co-added spectra, after measuring the RV, checking for binarity, and velocity shifting to the barycentric frame. Co-added spectra are used then to reject cosmic rays from individual spectra

In addition, “development pipelines” will be operated in-house (Keele and CASU) to identify and test possible enhancements to be suggested for the ESO pipeline. These also substantially assist quality control diagnostics (Sect 6) and will allow testing and assessing the influence of a variety of sky-subtraction, wavelength calibration, and telluric-removal techniques.

Telluric effects in both UVES and GIRAFFE spectra will be removed using calibration spectra of hot featureless stars. In addition, model telluric spectra will be utilised, and compared with the direct observational technique.

#### 4.3.3 Radial velocity (WG8)

After pipeline processing to remove instrumental signatures, extracted individual UVES and GIRAFFE spectra with their variance spectra and quality control flags are available. These are analysed (in one method, iteratively in pixel space, prior to final extraction) to deliver RVs (and rotational velocities  $-v\sin i-$  where relevant), and associated error functions, using separate pipelines for GIRAFFE and for UVES.

All spectra will be iteratively matched against a range of templates using the output from the classification process (below) to identify the most suitable object-specific templates, thus determining the output RV, and its probability distribution function.

Spectra for each target are velocity-shifted to the barycentric frame. Repeat (non-variable) spectra are optimally combined. Reduced spectra will be normalized in a standardized way. Specifically, normalization of

the continuum to unity will be performed by dividing reduced 1-D spectra by a smooth approximation of the continuum.

#### 4.3.4 Object classification (WG9)

The objective of this task is to *i*) provide a top-level object classification (e.g. stars vs. quasar or galaxy contaminants) for field targets; *ii*) to deliver a first estimate of stellar astrophysical parameters (APs – effective temperature, surface gravity) for every target category. Each object observed, together with all its associated photometry from the target selection process, is classified, through dedicated systems: these include cross-correlation with templates, neural networks, SOM, and the DPAC-Gaia systems (SVM, ILIUM), providing first-pass parameters for the spectrum analysis teams. Separate classification systems involving just photometry, and photometry plus the spectrum, will be implemented.

Both co-added and epoch spectra are then available for the analysis teams. The object classification algorithms additionally provide objective quality control information for every spectrum.

To minimise resampling of spectra we will maintain extracted spectra in natural units (pixel-based fluxes) and use FITS table extensions and/or FITS header information to specify conversions to physical units and/or zero-velocity systems when appropriate.

### 4.4 Spectrum analysis (WG10,11,12,13,14)

The spectrum analysis will be performed by five WGs; WG10 and WG11 will perform the analysis of GIRAFFE and UVES spectra of normal FGK stars; WG12 will focus on cool pre-main sequence (PMS) stars; WG13 will analyse hot stars; WG14 will be devoted to unusual objects, such as white dwarfs, close binaries, etc. The task of the five WGs is to process extracted spectra to refine astrophysical parameters, to deliver elemental abundances to a level appropriate for the relevant stellar type and available SNR, to derive stellar properties (e.g. activity, accretion, rotation -whenever relevant) and to provide detailed analysis-level quality-control.

It is a strength of this Gaia-ESO Survey team that it includes a majority of Europe's spectrum analysis groups, which between them have available expertise in several complementary standard, as well as special-purpose, spectrum analysis methodologies. This ensures that a full analysis, including any assumption-dependent and method-dependent systematic effects, will be implemented. Also, some of the methods that will be used in the analysis are also Gaia-DPAC algorithms.

The structure of the WGs on spectrum analysis provides close coordination between the teams, ensuring the optimum range of analyses will be applied to the various stellar and data types as appropriate. The methodologies are all established, all publicly well-documented, forming the basis of most modern spectrum analyses in the literature. Below we provide a general description of the input data, as well as of the strategy and methods to be followed by the spectrum analysis WGs.

#### 4.4.1 Input

The main input to the spectrum analysis WGs consists of reduced spectra. These have been put on a wavelength scale, have been velocity shifted to a barycentric reference frame, and have been normalized. Quality information is also provided, including variance spectra, SNR ratio, non-usable pixels, etc. Additional inputs are the radial and rotational velocities derived by WG8, photometric data, and first guess atmospheric parameters derived by WG9. For cluster stars, cluster distances and reddening values will also be available as input to the spectrum analysis.

Line lists, atomic and molecular data (gf-values, broadening constants, etc.) adequate for the different categories of targets and spectral intervals are compiled by the WGs prior to the beginning of the analysis and distributed among the analysis nodes. These actions are taken to ensure homogeneity in the derived quantities. Similarly, all the nodes participating in the analysis have adopted a fixed set of model atmospheres, which is sufficiently broad to be optimised for each class of Survey astrophysical targets.

#### 4.4.2 Analysis: strategy and methods

The five WGs in charge of the spectrum analysis will all follow a similar approach, summarized in the following.

- The data analysis will be both distributed and duplicated among the nodes contributing to each WG. Specifically, more than one group is expected to analyse and produce results for (nearly) all relevant Survey targets. This duplication of different methods allows, given performance comparison of the results, production of a set of recommended parameters. It also, through rigorous quality control, provides a quantitative estimate of both random and method-dependent uncertainties. In the event of discordant results for a specific star, individual checks will be conducted. A number of tests have already been performed to confirm the performance of the codes and the homogeneity of the results. [These tests also quantify the FTE effort required for the analyses.] Quality monitoring and outlier detection are performed throughout the Survey. Monitoring of homogeneity will be conducted by the analysis teams, in coordination with WG15 (see below). The decision on the final recommended values is the responsibility of WG15
- A first pass analysis will be performed, followed by a more refined analysis. The first pass analysis will quality check the classification parameters from WG9 and will provide APs, which, together with the information on photometry from the target selection procedure, are input to subsequent analyses
- depending on the star's spectral-type and characteristics, appropriate optimal tools, software, and model atmospheres are used; however, some methodologies in common to all WGs are identified. The methods to derive APs and abundances can be roughly divided in two broad categories. The first one includes the main types of parametrization methodology, such as exhaustive search algorithms, global optimization methods, projection algorithms, pattern-recognition methods, and Bayesian parametrization approaches; the second one consists of more classical approaches, based on measurements of equivalent widths (EWs) of absorption lines and inversion codes, or use of curves of growths (COGs) for particular lines/elements (e.g., Li). EWs are measured with (semi-)automatic codes by fitting Gaussian profiles to the lines. The available codes include: DAOSPEC, ARES, and SPECTRE. Additional methods to derive APs might be used in special subsets of the sample (e.g., H $\alpha$  wings, line-depth-ratios). In most cases the codes are automatic, and proven to be able to handle Gaia-ESO scale data

More specific details on the analysis of the different types of stars/spectra are given in the following sections.

#### 4.4.3 “Normal” FGK stars (WG10, WG11)

These two WGs, for UVES and GIRAFFE spectrum analysis, receive reduced UVES and GIRAFFE spectra of F-, G-, and K-type stars and, depending on the targets, produce a number of advanced data products: EWs, APs, elemental abundances, chromospheric activity indicators, and emission line measurements.

The activities of both spectrum analysis WGs are coordinated through a work package substructure that will manage the work related to auxiliary data (line lists, model atmospheres, synthetic spectra grids), atmospheric parameter determinations, individual abundance determinations, and non-LTE and 3D abundance corrections. The WGs will work in close collaboration. To ensure consistency several stars of different spectral-type will be observed with both UVES and GIRAFFE. A common coordination group for the analysis of FGK stars has been established. This group includes R. Smiljanic and A. Korn (UVES analysis), A. Recio Blanco and C. Allende Prieto (GIRAFFE analysis), L. Pasquini and V. Hill. The group was established to ensure that issues involving both analysis groups can be discussed and common decisions reached. The group is also responsible for communication with other WGs and the Steering Committee, and to ensure documentation of the analyses. One single set of 1D model atmospheres (MARCS models from Uppsala) will be used for the analysis of both UVES and GIRAFFE spectra, ensuring homogeneity between the results.

First pass analysis, aimed to check and refine APs from WG9, will be carried out using Nelder-Mead (global optimization), MATISSE (projection), and DEGAS (pattern recognition).

Methods to derive a final set of APs (including microturbulence  $-\xi$ ) and abundances include those three above, plus Spectroscopy Made Easy and MyGIsFos (exhaustive search), as well as MOOG (EWs). Whilst all these methods will in general be applied to both GIRAFFE and UVES spectra, it is useful to recall here that the two WGs will deal with spectra of different types of targets, resolving powers, spectral intervals, SNR ratios, and, number of stars. Also, UVES spectra will yield abundances for a significant larger number of elements than GIRAFFE ones. Therefore, depending on this, choice of specific methods to be applied to the different type of spectra may vary.

**UVES spectra** The following classes of stars will be observed with UVES fibres: Clump and RGB giants in intermediate-age and old open clusters, and in the Galactic bulge and outer thick disc, FG dwarf and subgiant stars in both the solar neighborhood and in intermediate age open clusters. In total, between 5,000 and 10,000 spectra are expected. All stars will be observed with UVES 580-nm setting, at a resolution  $R \sim 45,000$ . For all stars, output products include EWs, precise APs, and elemental abundances for several elements. Chromospheric activity and emission line measurements will be provided whenever relevant.

EWs will be mainly measured using the tools listed above. For particular features, e.g. some weak lines of neutron capture elements, or strong lines of Na and Mg, non-automatic spectral fitting, allowing for non-Gaussian profiles, will also be employed.

Final APs and elemental abundances will be derived with the methodology described above. In particular, abundances will be calculated using both EWs and via fits to synthetic spectra. Elemental abundances are provided per star both on a line-by-line basis and average values per element. Uncertainties induced by the atmospheric parameters and quality flags are provided for the average values. For elements with more than 3 lines, the standard deviation of the average is also provided. Severely discrepant lines might be removed based on an informed evaluation of the reasons for their deviating nature (e.g., wrong line parameters, poorly defined continuum, NLTE effects, etc.). The number of elements to be constrained will be maximized, but will critically depend on SNR.

**GIRAFFE spectra** FG dwarfs in the thick disc and halo, K giants in the bulge, and solar-type stars in intermediate age and old clusters will be observed with GIRAFFE. Several settings will be used, all yielding a resolution  $R \sim 20,000$ . Some  $10^5$  stars will be observed.

Given the very large number of stars, determination of the APs and individual abundances is automated in most cases, using the codes listed above. Some of these methods utilise the initial estimates of the atmospheric parameters furnished earlier in the reduction chain by the classification algorithms. Sub-sets of the line list used for the UVES analysis and optimised for cool giants and warm FG dwarfs, respectively, will be employed. Output products are the same as for UVES, although a smaller set of elemental abundances will be derived from GIRAFFE spectra (see Sect. 7).

#### 4.4.4 Cool pre-main sequence stars (WG12)

Spectrum analysis of cool, low-mass members of young clusters will be performed by a dedicated WG, due to the diversity of spectral characteristics, in particular the possible presence of spectral-veiling, and of emission lines due to accretion, and to the fact that these stars extend to much later spectral-types.

UVES fibres will be allocated to PMS or zero age main sequence late-G and K-type stars, while GIRAFFE fibres will target K- and M-type cluster members. All UVES targets will be observed with the 580-nm setting, while for GIRAFFE the HR15n and/or the HR21 will be employed. A few hundreds and a few thousands UVES and GIRAFFE spectra, respectively, are expected.

A first pass estimate of parameters (veiling, spectral-types, temperature, surface gravity,  $[\text{Fe}/\text{H}]$ , rotational velocities) will be applied to both UVES and GIRAFFE spectra. It will be mainly performed using ROTFIT, an automatic code estimating stellar parameters by comparison with a library of observed spectra (minimum of the residuals method). Similarly, the amount of veiling will be estimated by comparison with available template spectra of stars of similar spectral-type as the target stars.

Second phase analyses will be distributed among the different nodes and will make use of different methods. These will include application of de-reddening and de-veiling schemes, as well as refined determination of  $T_{\text{eff}}$ ,  $\log g$ ,  $[\text{Fe}/\text{H}]$  for G- to M-type stars from GIRAFFE and/or UVES spectra; determination of chromospheric

activity index; determination of Li abundances; determination of precise elemental abundances from UVES spectra; determination of mass accretion and mass loss rates, whenever applicable. As in the case of normal FGK stars, the number of elements to be determined from UVES spectra will critically depend on the achieved SNR ratio and spectral-type.

Different sets of 1D model atmospheres will be used for the second phase analyses: MARCS models will be employed, in order to be homogeneous with the FGK spectrum analysis; for stars cooler than 4500 K, for which MARCS models may not be appropriate, the analysis will also be performed using NextGen and/or BT-Settl models. Performance comparison and quality control will be carried out throughout the Survey. Specific methods to be used for APs and [Fe/H] determination include again ROTFIT, as well as ARES, the UCM code, and MOOG and EW measurements; detailed elemental abundances will be derived using MOOG and the UCM code. Lithium abundances in stars cooler than 4000 K will be derived using curves of growths tailored to that class of objects.

Mass accretion and mass loss rates will be determined using non-automatic methods, based on the derived luminosities or widths of the several emission line tracers present in the UVES and GIRAFFE spectral ranges and available calibrations. Measurements of EWs (needed to derive line luminosities) or widths of emission lines will be performed using fitting of line profiles within the MIDAS or IRAF context.

#### 4.4.5 OBA stars (WG13)

This WG will focus on the analysis of the spectra of OBA-type stars. Analysis of a subset of FGK stars is also foreseen, to have some deliberate overlap with WG10 and WG11. For the hot stars UVES 520-nm setting and GIRAFFE HR03,05A,06,10/14A setups will be used. As in the case of cool PMS stars, a few hundreds and a few thousands, UVES and GIRAFFE respectively, spectra will be analysed.

Refined classification is provided by automated comparison to an optimised spectral atlas. This provides improved APs, and allows allocation of the spectrum to the optimal one of several analysis methods/groups.

General techniques that will be used both during first and second pass analyses used include the EWs as well as spectral-synthesis fitting (using, e.g. Nelder and Mead technique). FASTWIND and CMFGEN codes will be used for O-type stars. For each star, on the basis of combined (or epoch) spectra, the following parameters will be derived from the spectra: effective temperature and gravity; more accurate determination of radial and rotational velocity; for the earliest-type stars: mass loss rate from H $\alpha$  and He II 4686 Å; abundances: which elements will depend very much on the spectral-type.

#### 4.4.6 Non standard objects (WG14)

A special object-by-object analysis process will be applied to spectra which are not consistent with any of the stellar classes described above.

#### 4.4.7 Survey Parameter Homogenisation (WG15 & WG5)

The aim of this WG is to ensure that the data products generated by the spectrum analyses are coherent, the resulting stellar atmospheric parameters and abundances homogeneous, the parameters are calibrated onto an identified (set of) external calibrator objects, and the process is fully documented, supporting the data releases. This homogenization process is a key aspect of analysis quality control, and will proceed through a double iteration. The major part of this homogenisation process will be done inside each WG, where in particular the outputs of different analysis tools will be compared and combined. Bringing together a final “best” parameter set requires, in addition to the internal analyses, careful analysis of calibration targets, and targets observed in more than one setting and instrument. To ease cross-comparisons, it is important to define a common set of procedures among the different WGs. Much of this information is provided through WG16, which monitors Survey progress. Thus several teams are involved. Hence an important task of this WG is to provide a communications channel between all spectrum analysis WGs, ensuring verification all along the Gaia-ESO Survey project teams that the physical parameters and analysis tools employed by the different WGs

and nodes produce consistent results.

*Tools and procedures* An urgent but minor task is to maintain support for the common FITS-VOTable data format, used by all analysis teams (cf archive section below).

#### 4.5 Survey progress monitoring (WG16)

Survey progress monitoring is a major task, sufficiently critical to efficient Survey progress that the relevant WG (WG16) is led by the Co-PIs directly. Survey progress is a complex mix of management, communications, and book-keeping. Management involves monitoring the progress of all WGs involved in data preparation, processing, and analysis. The key aspect for this WG is the book-keeping. Reliable and quantitative information must track, for every target star, the number of observations attempted, achieved, and still awaited. The processing status of each observation must be tracked, and updated as each WG deposits data in the operational database. SNR data for each spectrum, SNR data for each object, including repeats and different settings, and necessary additional information prior to object readiness for science analysis, must all be maintained for all  $10^5+$  targets. For the clusters the same information must be maintained both for the individual targets and for the clusters as a whole. In particular, the fractional completion of data taking and processing for each cluster must be tracked. The CASU management system delivers this data to the Co-PIs (WG17).

Internal data management of data products is designed around the ESO FITS raw data structure. The extracted, wavelength calibrated and sky subtracted spectra will be in a 2d “image” with the corresponding fibre information in binary table extensions. Processing and QC information will be propagated through the FITS header. The outputs from all later stages of processing will be incorporated in further binary table extensions. This model, where all relevant information about an observation is kept in the same container file, operates well for the VISTA pipelines, and cuts bookkeeping tasks down to a minimum.

All analysis steps will be fully tracked and version controlled together with online access to Survey progress and quality control information (see e.g. for VISTA <http://casu.ast.cam.ac.uk/vistasp/>). The Survey progress information will be returned to the WP handling ‘Survey Monitoring’ allowing for input to the ‘Observation Preparation’ team defining which observational blocks need to be configured for future observations.

This WG is unique in that it monitors all Survey progress, not just data processing, but including science quality control activities. Science quality control aspects are understood, and will be implemented as science data become available.

#### 4.6 Operational database (WG17)

The Gaia-ESO project will utilise both an operational database and an archive, to hold all relevant information. This approach builds on the operational VISTA (etc) systems hosted at CASU, Cambridge, and WFAU, Edinburgh. It is a proven and successful model, and is essential to support the survey data flow. In particular, this approach keeps separate the day-to-day processing, the spectrum analyses, and all activities in which data are being determined or updated, from all those science activities which should be based on readily accessible static information.

The operational database holds all data which remains incomplete, or subject to change. All observation preparation WGs submit all relevant data associated with target selection, up to and including OB preparation, to the operational database [WG1-WG6]. Raw data from ESO are added. Pipelines [WG7-WG9] operate on the raw data, generate pipeline reduced and extracted spectra, with associated variances, QC info, RVs and classification outputs, and write these back to the operational database. An aspect of the QC is the quantitative SNR data supplied to ESO through the SPS-snr reports, cf. Sect 2.4. Spectrum analysis groups [WG10-WG15] read, but do not modify, these spectra, carry out their analyses, and deliver back FITS-table results to the operational database. These tables are attached to each relevant spectrum, allowing the progress monitor to be updated.

We will base the spectral extraction/reduction products format to conform to the standard ESO FITS structure

for FLAMES/GIRAFFE. These are multi-extension FITS files containing an efficient 2D storage of extracted spectra, plus associated corresponding FITS table information in extensions containing object and fiber information.

The primary output products, the extracted, wavelength-calibrated and sky-subtracted spectra, will maintain this format with the addition of a 2D error array corresponding to the extracted spectra format. The spectra, and error array, will be rebinned onto a common (specified) wavelength grid (range TBC).

Subsequent processing stages will collate and incorporate available existing information such as photometric indices, proper motions, and also append derived radial velocities and stellar atmosphere parameters in additional FITS table extensions.

To minimise resampling of spectra we also propose to maintain extracted spectra in natural units (e.g. pixel-based fluxes) and use FITS table extensions and/or FITS header information to specify conversions to physical units, should this ever be appropriate and required, and/or zero-velocity systems.

Further processing stages involving common tasks such as continuum estimation and normalization to unity can be readily be incorporated by including extra FITS extensions.

The philosophy is to keep the same file architecture throughout and minimise bookkeeping and versioning issues by always attaching information directly to the files. This also has the advantage of removing direct dependency on availability of access to external databases.

We use the Gaia DPAC model - all data are stored in the central repository, taken out for use/analysis, and have parameters returned. No process adjusts the spectra, except by resetting the master spectrum if needed when the whole process restarts from scratch. No data processing WG talks directly to the archive. When the spectrum teams agree their job is converged for some source, all relevant data become fixed.

At this stage all data are copied to the permanent Gaia-ESO archive, hosted at Edinburgh, and become available internally to begin science quality control.

It is clear that a major role for the operational database is to host the Survey progress monitoring information (cf Sect. 4.5 above).

## 4.7 Survey archive (WG18)

After pipeline processing, including atmospheric parameter and abundance determination etc., the spectroscopic Survey data will be made available to the consortium for quality control, science verification and preliminary analysis via a bespoke archive system. This system will act not only as the ‘internal’ archive system for the consortium, but also as a publicly accessible portal that will provide enhanced database-driven products to facilitate world community exploitation of prepared static releases of Survey data. Metadata associated with the products available in the archive will comply with the corresponding VO Data Models, in particular with the VO Spectrum Data Model. This follows the tried-and-tested Vista Data Flow System (VDFS) model developed by Cambridge and Edinburgh, for UKIRT-WFCAM, VISTA-VIRCam and VST survey data, and supports both internal team science verification, but all provides a global archive system complementary to that provided by ESO-SAF.

The Gaia-ESO Survey archive design will follow proven models, and will include the following features:

- back-end relational database management system store
- a near-normalised relational design to track all data, metadata and provenance through the pipeline and subsequent analysis stages
- simple interface applications for the novice user
- tabular data (i.e. catalogues) available through ConeSearch protocols

- SQL interface and relational model exposed to users through interactive web forms for more complicated usage scenarios
- integration of multi-wavelength catalogue data and image thumbnails
- publication of spectroscopic data to the VO through the Simple Spectral Access Protocol
- publication of all tabular data (e.g. input catalogues, derived physical quantities for targets etc.) to the VO through the Table Access Protocol (thereby making them accessible to sophisticated client-side exploration and analysis utilities such as TOPCAT)
- finally, cross-linking to the Gaia first release will either be provided in the archive or through (VO) protocols

#### 4.8 Survey outreach and communication (WG19)

Outreach to the wider community will be organized by WG19. This will ensure the fullest science community awareness and exploitation of the Gaia-ESO Survey. It is anticipated that the Gaia related GREAT network will be leveraged to allow for joint science workshops and exchanges supporting the science development of the Survey.

### 5 Manpower and hardware capabilities devoted to data reduction and quality assessment

This section tabulates the top-level data management tasks, the teams which have confirmed FTE support for those tasks, and the task coordinators. The Gaia-ESO consortium includes some 300 participants in over 90 institutes. Rather than list all, the table summarise the effort by WG. The detailed involvement at individual level, and more detailed task descriptions, are maintained on the Gaia-ESO Survey wiki. Not all groups are independent, some are distributed geographically, but here we list all the individual institutes.

All Gaia-ESO activities are under joint Co-PI responsibility, and, as described above, are allocated to a series of dedicated WGs, each with an identified coordinator, remit, requirements, and deliverables. The WG coordinators report to the Co-PIs through a Steering Group, which acts as the project management board. The Steering Group members, identified as experienced individuals, act to assist the Co-PIs in supporting the whole consortium activities. Steering group members are listed in the table below.

The Co-PIs are well aware of the realities and inefficiencies involved in a large, distributed, part-time, self-motivated team. However, the key and the time-critical tasks all have significant dedicated group effort identified. The pipeline processing, archive, and spectrum analysis groups in particular are large and very well supported. Those groups involved in handling significant data volumes have been involved in extensive simulations and optimisations, during project preparation, which involved data sets as large as the total Gaia-ESO data volume. Thus sufficient hardware and communications systems are already in place to handle the end-of-Survey requirements.

The Gaia-ESO Survey also has identified sufficient FTE effort for other Survey tasks which are not data management, such as interface to Gaia, ISM analyses, production of a uniform suite of stellar atmosphere models to support the spectrum analysis, and so on. They are not listed here.



Name	Function	Affiliation	Country
Gerry Gilmore	Co-PI	Institute of Astronomy	UK
Sofia Randich	Co-PI	INAF Obs Arcetri	I
M. Asplund	Steering Group	ANU/MPA	Aus/D
J. Binney	Steering Group	Oxford	UK
P. Bonifacio	Steering Group	Paris	Fr
J. Drew	Steering Group	Herts	UK
S. Feltzing	Steering Group	Lund	Se
A. Ferguson	Steering Group	Edinburgh	UK
R. Jeffries	Steering Group	Keele	UK
G. Micela	Steering Group	Palermo	I
I. Negueruela	Steering Group	Alicante	Sp
T. Prusti	Steering Group	ESA	ESA
H-W. Rix	Steering Group	MPIA	D
A. Vallenari	Steering Group	Padova	I

Function	Contributing Groups	FTE/yr	Coordinators
Survey Overview	Co-PIs	2x0.4	Gilmore, Randich
Management Overview	Steering Group	12x0.1	12 members
Paranal Observations	<b>WG0:</b> ESO, Lund, MPiA, Padova	0.4	T. Bensby (Se)
<b>Target selection, Calibrators, FPOSS &amp; OBs</b>			
Open Clusters: membership analysis auxiliary data target selection	<b>WG1,2,4:</b> Alicante, Armagh, Torino, ETH, MSSL Vienna, MPIA, Palermo, Barcelona, Granada Bologna, Madrid (CAB), ESO, ESA, Geneva, AIP Herts, Arcetri, Uppsala, ROBelg, Leicester, Indiana, Graz, Lisbon, Grenoble Keele, IAC, Athens, Exeter, Birmingham Padova, Catania, Porto, Nice, ZAH	6	E. Alfaro (Sp) E. Paunzen (At) A. Bragaglia (I)
Galactic Plane & Field Selection	<b>WG3:</b> Camb, ZAH, ANU, MPIA, Paris, RUG, AIP, MSSL, Strasbourg, Oxford	4.5	C. Babusiaux (Fr)
Calibrators & Standards	<b>WG5:</b> AAO, AIP, Uppsala, Camb, Bordeaux Antwerp, Bologna, Madrid, Paris, MPA, ANU	1.5	E. Pancino (I)
OB/FPOSS generation: Field Survey Cluster Survey	<b>WG6:</b> Paris, ESO, Camb, Lund, AIP, ZAH Arcetri, Bologna, Catania, Padova, Palermo, IAC Exeter, Alicante, CAUP, ESO	1 2	T. Bensby (Se) E. Flaccomio (I)
<b>Spectrum Extraction Pipelines</b>			
Pipeline Raw Data: GIRAFFE Reduction UVES Reduction	<b>WG7:</b> CASU, Keele Arcetri	1 2	M. Irwin (UK) L. Morbidelli (I)
Radial Velocities	<b>WG8:</b> Camb, Keele, Arcetri, Antwerp, ZAH	2	Camb/Keele/Arcetri
Discrete Classification	<b>WG9:</b> Camb, MPIA, IAC, Madrid, MSSL, Porto, ZAH	2.5	S. Koposov (UK)
<b>Spectrum analyses</b>			
FGK Stars: GIRAFFE incl QC	<b>WG10:</b> Paris, MPA, Lund, Uppsala, Nice, Bordeaux Arcetri, Bologna, Liège, Geneva, Alicante Nice, ESO, Porto, ZAH, Arcetri, Naples Catania, Padova, Kaypten, IAC, ANU	17	A. Recio-Blanco (Fr) & C. Allende Prieto (Sp)
FGK Stars: UVES incl QC	<b>WG11:</b> Paris, MPA, Lund, Uppsala, Nice, Vilnius Arcetri, ANU, Bologna, AIP, Indiana, UCM, Herts Groningen, ESO, Naples, Porto, Catania, Alicante Padova, Liege, Bordeaux, ZAH, IAC, Chile	14	A. Korn (Se) & R. Smiljanic (ESO)
WG10/11 Interface	Recio-Blanco, Allende Prieto, Pasquini, Smiljanic, Korn, Hill	0.5	
Pre-Main-Sequence stars incl QC	<b>WG12:</b> Arcetri, Catania, IAA Naples, Palermo, ETH, CAUP Keele, Exeter, Madrid (UCM, CAB)	8	A. Lanzafame (I)
OBA Stars incl QC	<b>WG13:</b> Liege, RO Belg, AIP, IAC, OMA, Madrid, Paris Alicante, Uppsala, MPIA, ZAH, Leuven, Herts Calar Alto, Nice, IAA, IAC, Armagh	2	R. Blomme (Be)
Unusual Objects incl QC	<b>WG14:</b> SRON, Nijmegen, Warwick, IAC, Leuven MPIA, Herts, IAC, ZAH	1	S. van Eck (Be)
<b>Quality Control, Parameter Homogenization</b>			
Survey Parameter Homogenisation	<b>WG15: &amp; WG5:</b> all spectrum analysis groups	4	P. Francois (Fr)
<b>Survey monitoring, database, archive</b>			
Survey Progress	<b>WG16:</b> CASU	0.5	Co-PIs
Operational database & Phase 3	<b>WG17:</b> CASU/Cambridge	0.5	CASU
Survey Archive	<b>WG18:</b> AIP, RUG, Madrid, Vienna, ZAH, Edin	0.6	N. Hambly (UK)
Outreach	<b>WG19:</b> Cambridge	0.1	N. Walton (UK)

## 6 Data quality assessment process

Each data product delivered by the Gaia-ESO Survey (see Sect. 7 below) will include a measurement of variance, quality control parameters and/or quantification of both random and systematic analysis-dependent errors. Quality assessment will be recorded in the archive. This section describes the quality control process that will be applied to the various data products.

### 6.1 Reduced, one dimensional spectra

- UVES: quality assessment will be performed as part of the UVES reduction pipeline and consistently with the methodology followed by the internal ESO quality control. The following items will be checked:
  - confirm appropriate selection of calibration data
  - flag any peculiarities in the raw data, like e.g. unusual bias level.
  - assess the cross-dispersion profile: this checks the exposure level, the sky background, and possible light contamination between adjacent fibres
  - assess the mean intensity per fibre: this gives an indication whether the complete fibre has been extracted correctly
  - sanity-check the dispersion solution
  - check the positions of frequent lines are correct, e.g. the Na I doublet, Li absorption line, H $\alpha$ , etc.
  - visual check: the full spectrum and its variance are plotted and checked visually for anomalies in the extraction

The SNR of each extracted spectrum will be computed in different spectral regions and will be compared with the expectations, given the star magnitude and the recorded observing conditions. Each reduced dataset will have associated QC reports and plots, for each detector and each fibre.

- GIRAFFE: the key steps in the calibration analysis flow whose implementation is checked through the relevant variance spectra and reduction pipeline diagnostics include: file metadata check, cross talk correction, bias and dark correction, aperture localisation and tracing, scattered light correction, 2d profile fitting, optimal extraction, wavelength calibration, flat-field and throughput correction. In addition to these “standard” steps, tailored sky subtraction and continuum estimation stages will be available as a precursor to first-pass RV estimation. The spectrum variance is calculated during pipeline processing. The SNR of each extracted spectrum will be calculated, and compared with expectation given object photometry and recorded observing conditions. The parallel GIRAFFE reduction pipelines allows us to attain a crucial quality control measure and to assess the influence of different reduction approaches

Independent quality control at the extracted spectrum stage, for both UVES and GIRAFFE data, is provided by the discrete classification processes. These use a variety of methods to compare a spectrum with both standard spectral libraries, and all other spectra. Outliers and anomalies are identified with very high reliability, and will be checked individually. Clustering analyses on the classification outputs are an objective robust quality control measure of extracted data.

### 6.2 Radial velocities

The RV determination process derives a probability distribution function of the error for every spectrum. Unusual error PDFs are immediately evident. Radial velocity zero points are automatically checked against sky lines during RV calculation, and RV standards. Also, use of parallel pipelines will give us the opportunity to assess the effects of different wavelength calibration/correction strategies and RV determination algorithms. Since kinematic analyses are a major science motivation for the Gaia-ESO Survey, for both field and cluster member stars, careful scientific quality control of the RVs will be delivered by the Gaia-ESO Survey team.

### 6.3 Stellar parameters and abundances

Establishing a well-quantified set of calibration stars is a high priority for the Gaia-ESO Survey. Very careful analyses and repeat observations are an aspect of this calibration. These naturally provide a key data set for internal quality control, in addition to their wider value.

The top-level view of the Gaia-ESO spectrum analysis quality control is as follows: A design consideration in the Gaia-ESO Survey is to ensure that several complementary analyses of each spectrum are implemented. The consistency of the results of the several methods, and the sensitivity of specific results to analysis assumptions, will deliver, for each star target, a “best” set of parameters and abundances, and quantified corresponding random and systematic errors. As part of the internal quality control process, analysis of the effect of alternative analysis assumptions will be available. All these results will be archived for later analysis. The reduced data will be sanity checked, results for the calibration targets analysed, errors assessed and verified. Before final acceptance, the anticipated deliverables will be subject to internal Gaia-ESO science verification. As for the RVs, analysis of abundance distributions is a major aspect of Gaia-ESO Survey science, so that careful detailed analyses of parameter values and distribution functions will be a team priority. Following this process, checked deliverable data products will be available in the archive and the operational database.

At a more detailed level, the quality control proceeds as follows: Spectrum analysis WGs will analyse reduced spectra which have already passed standard pipeline and classification algorithm quality control procedures. Only a quick additional check on the input reduced spectra will therefore be performed. This consists in ensuring that the data contain no NaNs nor Inf (or only a limited number of them in well identified regions), that the range of wavelength and flux are as expected, that the spectrum “looks plausible”.

The spectrum analysis WGs will adopt coherent procedures both for the analysis itself and the data quality assessment process. Specifically, analysis providing first pass parameters will automatically identify spectra of peculiar objects or spectra containing errors, since the minimum deviation derived from the comparison with spectra of known objects will be above the expected value. These spectra will be flagged as “unexpected feature” before the start of the refined analysis phase. During this phase each spectrum will be analysed by a (semi)-automatic code (if of sufficient SNR) and at least by one not-automatic procedure. Spectra flagged as “unexpected feature” will be analysed by at least two not-automatic procedures. The application of not-automatic procedures may further flag spectra with unexpected features.

Following spectrum analysis, the following quality control procedure will be applied to set/unset QC flags:

- Comparison of the parameters derived for the same spectrum with different methods and from the different nodes. Do these agree within the expected uncertainties? Deviating parameters from one or more methods will define method-dependent systematics
- Do parameters derived from different spectra of the same object exceed the expected variance for the class the object belongs to?
- Do the parameters deviate by more than a given value from expected ranges set by prior information on the class of objects the target belongs to?
- Comparison of stellar parameters and abundances of target stars observed with both UVES and GIRAFFE
- Consistency of object-specific checks with discrete classification outcomes

## 7 External Data products and Phase 3 compliance

The Survey will yield GIRAFFE spectra for  $\simeq 10^5$  stars, UVES spectra for  $\simeq 10^4$  stars, most of which are observed at two different epochs. Raw data will automatically be public. The products to be delivered during Phase 3 include extracted spectra, with relevant ancillary information, and value added deliverables, along with information on the data.

The Survey requires several observations of each target star to provide sufficient information to initiate spectrum processing and analysis. Thus we distinguish carefully between the time when a spectrum is taken, and the time when all spectra for a target are delivered, at suitable SNR. It is this second date which initiates the timing for release of advanced data products. See also Sect 8 below. Regular data releases to ESO will include, for all targets with completed observations:

1. **Semester Advanced Data Product Releases** These are the outputs of Working Groups 1-9.

- One-dimensional, wavelength calibrated, sky-subtracted, normalised, UVES and/or GIRAFFE spectra for each Survey target, extracted using the current ESO pipelines. Where no RV variability is detected, co-added sum spectra will be provided, in addition to single-epoch spectra. UVES spectra will be provided as sets of single echelle orders and a merged spectrum
- The associated variance spectrum
- Associated quality control information
- Supplementary value-added data
  - The photometry (and additional membership information for clusters) used to select the targets
  - Object classification
  - Radial velocity and its error distribution function
  - Analysis for RV variability
  - Projected rotational velocity and error estimate (where relevant)

2. **Annual Advanced Data Product Releases** Advanced data products from expanded and refined spectral analysis, calibrated using the current Gaia-ESO calibrations. These are the outputs of iterative homogenization and quality control involving Working Groups 10-15, and science verification analysis.

- **For stars observed with GIRAFFE:**
  - Whenever possible stellar astrophysical parameters: effective temperature, surface gravity
  - Equivalent widths of absorption and emission lines (when present)
  - Whenever possible stellar metallicity [Fe/H]
  - Whenever possible  $[\alpha/\text{Fe}]$  ratios
  - Measurements of stellar activity or mass accretion/ejection rates, for cluster members (where relevant)
  - Quantitative mass loss estimates, for early-type stars
  - Elemental abundances, with the specific elements depending on target type.
  - Quantitative uncertainties on the delivered quantities, derived from the multiple reduction systems implemented
- **For stars observed with UVES:**
  - Stellar astrophysical parameters: effective temperature, surface gravity, microturbulence
  - Stellar metallicity [Fe/H]
  - Equivalent widths of absorption and emission lines (when present)
  - Elemental abundance estimates for some or all of the following elements (where stellar abundance and astrophysical parameters permit) Li, C, O, Na, Mg, Si, Ca, Sc, Ti, Cr, Mn, Ni, Zn, Y, Zr, Ba, La, Ce, Eu
  - chromospheric activity measurement, when relevant
  - Quantitative uncertainties on all the above parameters, derived from the multiple reduction systems implemented

The data release will also include selected matched multi-wavelength photometric data for each source. The amount of such data will increase with time during the Survey as on-going surveys become public.

3. **Final Advanced Data Product Release** This final data-release (cf §7) will include best values for all deliverables listed above for all stars, calibrated onto the final Gaia-ESO calibration system. In addition, for open cluster members, it will include

- Average RV for the clusters
- Refined membership classification
- Binarity flags
- Cluster mean metallicity determinations with standard deviation
- Cluster mean elemental abundances with standard deviations

Following the agreed schedule, and after validation and Co-PI sign-off, the Survey products will be delivered to the ESO Science Archive Facility (SAF) during Phase 3 and will comply with the data standards and policies which are published on <http://www.eso.org/sci/observing/phase3.html>. Each release will be supported by a release description that specifies content, data properties, and format.

## 8 Timeline for delivery of data products to the ESO archive

Data releases are subject to the following constraints and opportunities.

- A large fraction of stars are observed in more than one GIRAFFE wavelength setting, very often with more than one integration per setting. Spectrum analysis must wait until all observations are available for a specific target and have the relevant SNR
- For clusters, star by star analysis has requirements as above, while full analysis requires complete observations on all cluster targets;
- Gaia-ESO invests considerable effort in calibration. The science requirement is to be reliable, inevitably at the cost of time invested. The calibration will improve with Survey progress. Reliable advanced data products must await acquisition and analysis of calibration targets. Similarly, as calibration increases and improves, the Gaia-ESO Survey will derive and deliver revised astrophysical parameters from early observations;
- A strength of the Gaia-ESO Survey spectrum analyses is implementation of many techniques. This identifies systematic method-dependent effects to complement the random errors. Iterative parameter homogenization and quality control is required to converge on final parameters. Considerable post-analysis effort is required to deliver this advanced product.

The data products delivered from the Gaia-ESO Survey will be made public in three steps/categories (see Sect 7).

- **Semester Advanced Data Product Releases** Half-yearly deliveries to ESO of reduced 1-D spectra, associated variance spectra, RVs, variability information, and basic data for all targets for which data collection is completed to the relevant SNR six months before the data release. The first half-yearly data release will occur one year after official start of the operations ( $t_0 + 12$  months); first observations ( $t_0$ ) are scheduled for the night 31-12-2011. Thus, the first data release is scheduled for 01/2013 and will contain data for all targets for which data taking is complete prior to 30-06-2012. Nine semester data releases are anticipated.
- **Annual Advanced Data Product Releases** Four annual data releases to ESO of value added data products, including astrophysical parameters, element abundances, complementary data as appropriate, and uncertainties, for all targets for which data collection is completed to the relevant SNR six months

prior to the data release.

The first annual data release is scheduled for ( $t_0 + 18$  months) 06/2013 (P91). The first annual data release will contain data for all targets for which data taking is complete prior to 31-12-2012.

- **Final Advanced Data Product Release** A final data release, involving the full determinable set of astrophysical parameters for each individual target, and for the open clusters as systems, with updated and consistent calibration, as described in §7.

This final data release is expected to be no later than 24 months following final data taking.

While it is beyond the control of this project, current expectation is that the first major Gaia data release will become public around the time of Gaia-ESO Survey Data Release 3, allowing substantial scientific synergy between Gaia-ESO and Gaia. If Gaia data are available prior to the final data release of the Gaia-ESO Survey, explicit linking of each target to Gaia data will be provided. If Gaia data are later, linking through VO protocols at the Gaia-ESO archive will be implemented.

## 8.1 Project Review Schedule

- **Review 1** The set of milestones to be assessed by the progress reviews by the ESO PSSP are included in the Annual Advanced Data Product Releases. The first such review, planned to follow 24-months of Survey operation, naturally follows the first Annual Advanced Release, which is scheduled for mid P91. The first review will be in P92.
- **Review 2** The second review is to consider time replacement for poor observing conditions, weather and technical downtime, and survey continuation through year 5. This second review needs to be appropriately timed to allow optimisation of weather replacement time, and final year observations (notionally P96 and P97 for the five-year Survey plan). This review is anticipated in P94.

## 9 Acronyms

**AMBRE** ESO-Obs Cote d'Azur project to analyse ESO archive spectra

**AP** Astrophysical Parameter

**APOGEE** Apache Point Observatory Galactic Evolution Experiment

**ARES** Automatic Routine for line Equivalent widths in stellar Spectrum

**BT-Settl** a set of stellar atmosphere models

**CASU** Cambridge Astronomical Survey Unit

**CLR** Clear Sky (at Paranal Observatory during observing)

**CMD** Colour Magnitude Diagram

**CMFGEN** CoMoving Frame GENeral spectrum analysis code

**COG** Curve Of Growth

**Co-PIs** Co-Principal Investigators

**CoRoT** COnvection ROTation et Transits planétaires

**CPL** (ESO) Common Pipeline Library

**DAOSPEC** Dominion Astronomical Observatory SPECTrum analysis code

**DEC** Declination

**DEGAS** DEcision tree alGORITHM for ASTrophysics

**DENIS** Deep Near-Infrared Sky Survey

**DPAC** (Gaia) Data Processing and Analysis Consortium

**ESO** European Southern Observatory

**ESA** European Space Agency

**EW** Equivalent Width

**FASTWIND** a spectrum analysis code

**FITS** Flexible Image Transport System

**FLAMES** Fibre Large Array Multi Element Spectrograph

**FPOSS** Fibre Positioner Observer Support Software  
**FTE** Full Time Equivalent  
**Gaia** ESA's Astrometric mission  
**GIRAFFE** Medium-high resolution spectrograph (VLT)  
**gK** K-giant (star)  
**GREAT** Gaia Research for European Astronomy Training  
**HERMES** High Efficiency and Resolution Multi-Element Spectrograph  
**HRnn** GIRAFFE grating settings  
**ILIUM** An iterative local interpolation method algorithm  
**Inf** Bad data flag  
**IRAF** Image Reduction and Analysis Facility  
**ISM** Inter-Stellar Medium  
**log g** logarithm of stellar surface gravity  
**MARCS** a grid of one-dimensional, hydrostatic, plane-parallel and spherical LTE model atmospheres  
**MATISSE** MATrix Inversion for Spectral Synthesis  
**MIDAS** ESOs Munich Image Data Analysis System  
**MOOG** An LTE Stellar Line Analysis Program  
**MyGIsFos** a spectrum analysis code  
**NaN** bad data flag  
**NextGen** a set of stellar atmosphere models  
**NGC** North Galactic Cap  
**OB** (ESO) Observing Block  
**O,B,A,F,G,K,M** star spectral-types  
**OC** Open Cluster  
**OPC** (ESO) Observing Programme Committee  
**OT** (ESO) Observing Tool  
**PDF** Probability Distribution Function  
**PMS** Pre-Main Sequence (star)  
**Pnn, nn=88 to 98** ESO observing period numbering  
**PS1** PanStarrs photometric sky survey (single telescope)  
**PSSP** (ESO) Public Spectroscopic Survey Panel  
**QC** Quality Control  
**RA** Right Ascension  
**RAVE** Radial Velocity Survey  
**RGB** Red Giant Branch (CMD)  
**ROTFIT** a spectrum analysis code  
**RRM/ToO** Rapid Response Mode Target of Opportunity **RV** Radial Velocity  
**SAF** (ESO) Science Archive Facility  
**SDSS** Sloan Digital Sky Survey  
**SGC** South Galactic Cap  
**SIMCAL** Simultaneous Calibration  
**SkyMapper** Southern Sky Photometric Survey  
**SMP** Survey Management Plan  
**SNR** Signal to Noise ratio  
**SOM** Self Organising Map (classification)  
**SPECTRE** an interactive spectrum analysis code  
**SPS** Spectroscopic Public Survey  
**SPS-obs** interim progress report to ESO after each observing run  
**SPS-snr** quantitative progress report to ESO after each semester  
**SQL** Simple Query Language  
**SVM** Support Vector Machine (classification)  
**ToO** Target of Opportunity  
**TOPCAT** Tool for OPERations on Catalogues And Tables  
**UCM Code** Abundance analysis code developed at the Universidad Complutense of Madrid  
**UVES** UV-Visual Echelle Spectrograph (VLT)  
**UKIRT** United Kingdom InfraRed Telescope



**VA** ESO Visiting Astronomer  
**VDFS** VISTA Data Flow System  
**VHS** VISTA Hemisphere Survey  
**VISTA** Visible and Infrared Survey Telescope for Astronomy  
**VLT** Very Large Telescope (ESO)  
**VO** Virtual Observatory  
**VOtable** Virtual Observatory Tabular data format  
**VIRCam** VISTA IR Camera  
**VST** VLT Survey Telescope  
**VVV** VISTA Variables in the Via Lactea  
**WEBDA** A comprehensive star cluster data base  
**WFAU** (Edinburgh) Wide Field Astronomy Unit  
**WFCAM** Wide Field CAMera (UKIRT)  
**WFI** (ESO) Wide Field Imager (at La Silla)  
**WG** Working Group  
**2MASS** Two Micron All-Sky Survey