WEAVE Advanced Processing System (APS)

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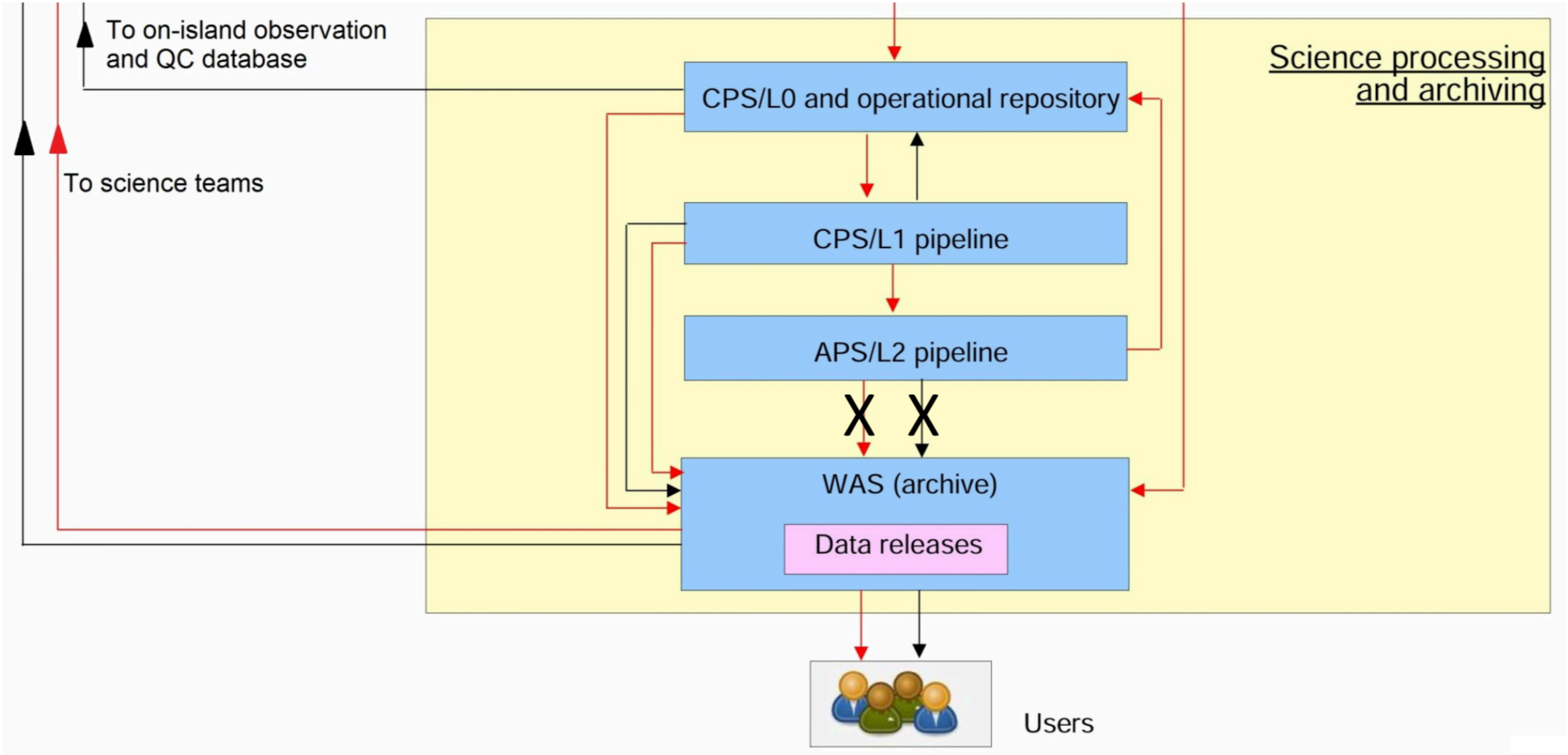
Tenerife, 14th November 2019

What is APS?

APS is part of the **WEAVE Science Processing and Analysis system (SPA)**, composed of specific science analysis tools (modules) allowing for the determination of astrophysical parameters (science-ready data products) relevant to the main survey object classes.



What is APS?

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PyAPS is a complete Python-based platform designed for overcoming the challenge of analysing, QC and visualising the WEAVE data. It consists of four components:

1- PyAPS.TARGETS: Data preparation, QC and visualisation package.

2- PyAPS.CLASS: Spectral classification and redshift fitting analysis package

3- PyAPS.STAR:

3.1- PyAPS.STAR.RV: A package to determine radial velocities and stellar atmospheric parameters

3.2- PyAPS.STAR.PyFerre: Measuring the stellar atmospheric parameters and elemental abundances

4- PyAPS.GALAXY: Stellar and gaseous components kinematics and populations analysis tool

Our strategy for developing the main processing components has been to adapt pre-existing/tested softwares. However, APS also hosts a set of guest modules, called Contributed Software (CSs).

APS Inputs (= CPS L1 outputs)

Science frames processed with the WEAVE reduction pipeline (BY WEAVE-CPS): Bias subtracted, flat-fielded, Spectral extraction, wavelength resampled and flux calibrated spectra for both MOS and IFU modes.

The structure of MOS L1 data

Extn	Extn Name	Description
0	**PHU**	This is the primary header unit.
1	**<arm>_DATA**	Final wavelength calibrated, sky subtracted and heliocentric corrected spectra.
2	**<arm>_IVAR**	The inverse variance of each spectrum (similar to a weight map).
3	**<arm>_DATA _NOSS**	The same spectra as in the first extension, but before sky subtraction.
4	**<arm>_IVAR _NOSS**	The inverse variance of the above.
5	**<arm>_SENS FUNC**	The sensitivity functions for each of the spectra.
6	**FIBTABLE**	A binary FITS table with information about each fibre that was used in the observation.

The structure of IFU L1 data cubes

Extn	Extn Name	Description
0	**PHU**	This is the primary header unit.
1	**<arm>_DATA**	wavelength calibrated, sky subtracted and heliocentric corrected flux.
2	**<arm>_IVAR**	The inverse variance of the above cube (similar to a weight map).
3	**<arm>_DATA _NOSS**	The same cube as in the first extension, but before sky subtraction.
4	**<arm>_IVAR _NOSS**	The inverse variance of the above.
5	**<arm>_SENS FUNC**	The sensitivity function for each of the spectra.
6	**<arm>_DATA _COLLAPSE**	A 2D image representing the cube in extension 1, collapsed along the spectral axis.
7	**<arm>_IVAR _COLLAPSE**	A 2D image representing the cube in extension 2, collapsed along the spectral axis.

And in what formats?

Observing Mode:	MOS	IFU (LIFU/mIFU)
Individual exposures [per arm]	**single_xxxxxxx.fit**	**cube/single_xxxxxxx.fit**
The files that result from a stack from within a single OB [per arm]	**stacked_xxxxxxx.fit**	**stackcube_xxxxxxx.fit**
Stacked spectra across OBs within a night or over many nights [per arm]	**super-stacked_xxxxx.fit**	**super-stackcube_xxxxx.fit**

Spectral classification Requirements

- **REQUIREMENT REQ-APS-05**

The software outputs shall be the **redshift**, uncertainties, and a **classification category** (independent from the user-provided category of the object).

- **REQUIREMENT REQ-APS-06**

It shall achieve an automated classification **success rate** higher than 90%. These rates are applicable to signal-to-noise (S/N)> 3.

- **OPTIMAL REQUIREMENT REQ-APS-07**

When the amount of data is large enough, the software will generate a new template set. All the spectra will be reanalyzed with new templates.

PyAPS.CLASS

Spectral classification and redshift fitting analysis package

- Based on **REDROCK** code, a state-of-the-art spectral classification and redshift fitting analysis software.
- Templates*:
    1. A suite of PCA templates and archetypes based on stellar population synthesis modelling of $0 < z < 1.5$ galaxies, generated from a custom high resolution theoretical spectra (Conroy, Kurucz, Cargile, Castelli, in prep.).
    2. Theoretical spectral models of stars (ATLAS9) and white dwarfs (Koester WD).
    3. A generative model of QSO spectra trained on spectroscopic observations for $2.2 < z < 6.0$.

* Once the WEAVE survey starts, APS will generate a new template set by selecting the best observed WEAVE spectra of each type.

PyAPS.CLASS MODULE OUTPUT STRUCTURE

Column	Description
1.**CLASS**	**Spectral classification. This field can be STAR, GALAXY or QSO**
1.**SUBCLASS**	**Spectral sub-classification. For galaxies this field can be AGN, STARFORMING, STARBURST or BROADLINE. For stars this field can be O, OB, B6, B9, A0, A0p, F2, F5, F9, G0, G2, G5, K1, K3, K5, K7, M0V, M2V,M1, M2, M3, M4, M5, M6, M7, M8, L0, L1, L2, L3, L4, L5, L5.5, L9, T2, Carbon, Carbon_lines, CarbonWD or CV.**
1.**Z**	**Barycentric Redshift.**
1.**Z_ERR**	**Redshift error based upon fit to $\chi 2$ minimum; NULL for invalid fit.**
1.**Z_all**	**An array of top 5 estimations of redshift**
1.**Z_ERR**	**An array of the redshift error for top 5 estimations**
1.RCHI2	Reduced $\chi 2$ for best fit template.
1.ZWARNING	A flag set for bad redshift fits.
1.SN_MEDIAN	Median S/N for all good pixels.

Stellar Analysis package Requirements

- **ESSENTIAL REQUIREMENT REQ-APS-08**

A. Determination of the fundamental atmospheric parameters **fine spectral types, RV, stellar parameters: T_{eff}, log g, ξ, [Fe/H] and [α/Fe].**

B. Derivation of other elemental abundances **elemental abundances [X/Fe].** Only to cool stars observed in the high resolution mode.

- **ESSENTIAL REQUIREMENT REQ-APS-09**

A. RVs with precision better than 2 km/s (LR) and than 0.5 km/s (HR)

B. T_{eff}, log *g*, [Fe/H]), and [α/Fe]) with a precision respectively better than 200 K, 0.3 dex, 0.2 dex, and 0.2 dex (LR);

and better than 150K, 0.2 dex, 0.1 dex and 0.1 dex (HR).

PyAPS.STAR.RV

An automated spectroscopic pipeline to determine radial velocities and stellar atmospheric parameters

- This module is a WEAVE-customised wrapper of the RVSPECFIT code (originally developed by Sergey Koposov).
- Templates: (PHOENIX v16)
  - The synthetic spectra cover the wavelength range from 500 Å to 5.5 μm with resolutions of R = 500 000.
  - The parameter space covers 2300 K ≤ Teff ≤ 12000 K, 0.0 ≤ log g ≤ +6.0, −4.0 ≤ [Fe/H] ≤ +1.0, and −0.2 ≤ [α/Fe] ≤ +1.2.

PyAPS.STAR.RV MODULE OUTPUT STRUCTURE

	Column	Description
	1.SNR	Median signal-to-noise ratio.
✔	1.**VRAD**	**Barycentric radial velocity.**
✔	1.**VRAD_ERR**	**Radial velocity error.**
	1.**SKEWNESS**	**skewness.**
	1.**KURTOSIS**	**Kurtosis.**
	1.**LOGG**	**Gravity *logg***
	1.**LOGG_ERR**	**Gravity *log* error**
	1.**FEH**	**Metallicity**
	1.**FEH_ERROR**	**Metallicity error**
	1.**ALPHA**	**Alpha-elements abundance *[α/H]***
	1.**ALPHA_ERR**	**Alpha-elements abundance *[α/H] error***
	1.**TEFF**	**Effective temperature T_{eff}**
	1.**TEFF_ERR**	**Effective temperature T_{eff} error**
✔	1.**VSINI**	**Rotational velocity**
	1.CHISQ	Chi-square of the best fit

PyAPS.STAR.PyFerre

Measuring the stellar atmospheric parameters and elemental abundances

- This module is a WEAVE-customised wrapper of the FERRE code (originally developed by Carlos Allende Prieto).
- **Templates**:
    - Cool Stars (ATLAS9)
    - Hot Stars (ATLAS9)
    - WD (Koester WD models)

	Library	$T_{\rm eff}$ (K)	$\log g$ (cm s^{-2})	[Fe/H]	[α/Fe]	$\log \xi$ (cm s^{-1})	n
Coarse Libraries	nsc1	3500:6000 (500)	0.0:5.0 (1.0)	−5:+0.5 (0.5)	0.5 at [Fe/H] ≤ −1.5, 0.0 at [Fe/H] ≥ 0, linear in between	0.176	432
	nsc2	5750:8000 (500)	1.0:5.0 (1.0)	−5:+0.5 (0.5)	–”–	0.176	360
	nsc3	7000:12 000 (1000)	2.0:5.0 (1.0)	−5:+0.5 (0.5)	–”–	0.176	288
	nsc4	10 000:20 000 (2000)	3.0:5.0 (1.0)	−5:+0.5 (0.5)	–”–	0.176	216
	nsc5	20 000:30 000 (5000)	4.0:5.0 (1.0)	−5:+0.5 (0.5)	–”–	0.176	72
Finer Grids	ns1	3500:6000 (250)	0.0:5.0 (0.5)	−5:+0.5 (0.25)	−1:+1 (0.25)	−0.301:+0.903 (0.301)	136 125
	ns2	5750:8000 (250)	1.0:5.0 (0.5)	−5:+0.5 (0.25)	−1:+1 (0.25)	−0.301:+0.903 (0.301)	101 250
	ns3	7000:12 000 (250)	2.0:5.0 (0.5)	−5:+0.5 (0.25)	−1:+1 (0.25)	−0.301:+0.903 (0.301)	86 625
	ns4	10 000:20 000 (500)	3.0:5.0 (0.5)	−5:+0.5 (0.5)	−1:+1 (0.5)	−0.301:+0.903 (0.301)	61 875
	ns5	20 000:30 000 (1000)	4.0:5.0 (0.5)	−5:+0.5 (0.5)	−1:+1 (0.5)	−0.301:+0.903 (0.301)	37 125

- These libraries cover the spectral range between 120 and 6500 nm, sampling the spectra with equidistant steps in log λ; for the R = 10 000 grids the step size is 1.434×10^{-5} , equivalent to ~10 km s^{-1}.
- In the finer grids, micro-turbulence is varied in constant steps of about 0.3 dex.
- The Coarse Libraries only consider three atmospheric parameters (Teff, Log g, [Fe/H]).
- The size of the finer libraries-files is much larger than the coarse ones, between a few and tens of gigabytes.

PyAPS.STAR.PyFerre

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    - Hot Stars (ATLAS9)
    - WD (Koester WD models)

PyAPS.STAR.RV MODULE OUTPUT STRUCTURE

Column	Description
1.SNR	Median signal-to-noise ratio.
1.VRAD	Barycentric radial velocity from XC code.
1.VRAD_ERR	Radial velocity error.
1.**TEFF**	**Effective temperature** T_{eff}
1.**TEFF_ERR**	**Effective temperature** T_{eff} **error**
1.**LOGG**	**Gravity** ***logg***
1.**LOGG_ERR**	**Gravity** ***log*** **error**
1.**MICRO**	**Microturbulence** μ_{micro}
1.**MICRO_ERR**	**Microturbulence** μ_{micro} **error**
1.**M_H**	**Metallicity** ***[M/H]***
1.**M_H_ERR**	**Metallicity** ***[M/H]*****error**
1.**ALPHA_H**	**Alpha-elements abundance** $[\alpha/H]$
1.**ALPHAH_ERR**	**Alpha-elements abundance** $[\alpha/H]$**error**
1.**PARAM_CHI2**	**Output covariances.**
1.**X_M**	**Individual abundance of the element X. Tentatively, X can be Si, Ca, V, Ni**
1.**X_M_ERR**	**Individual abundance of the element X**

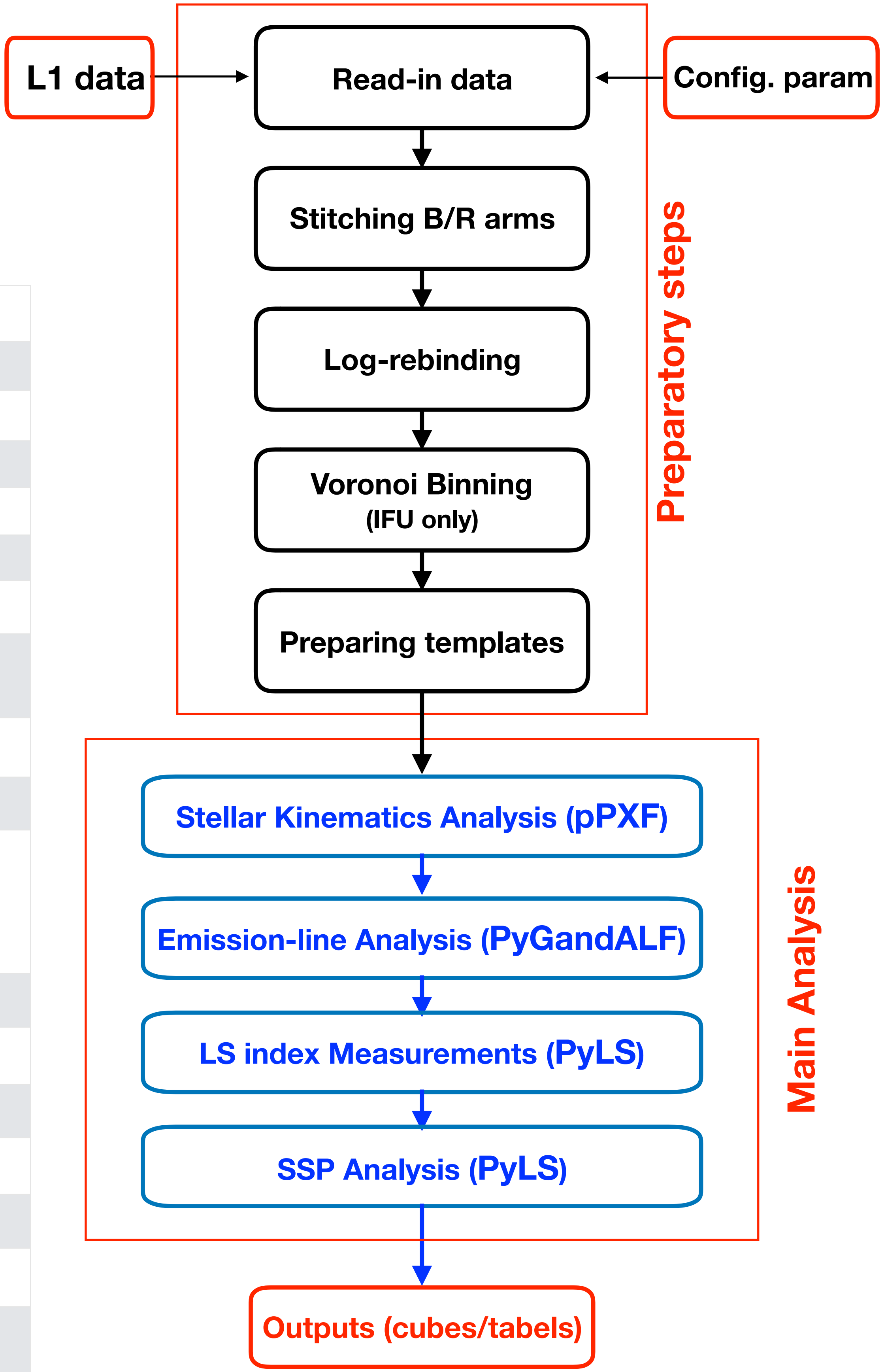
PyAPS.GALAXY (MOS mode)

Stellar and gaseous components kinematics and populations analysis tool

- A WEAVE(MOS/IFU)-customised version of the ***GIST*** pipeline (Binter el al. 2019).
- **Templates:** X-shooter

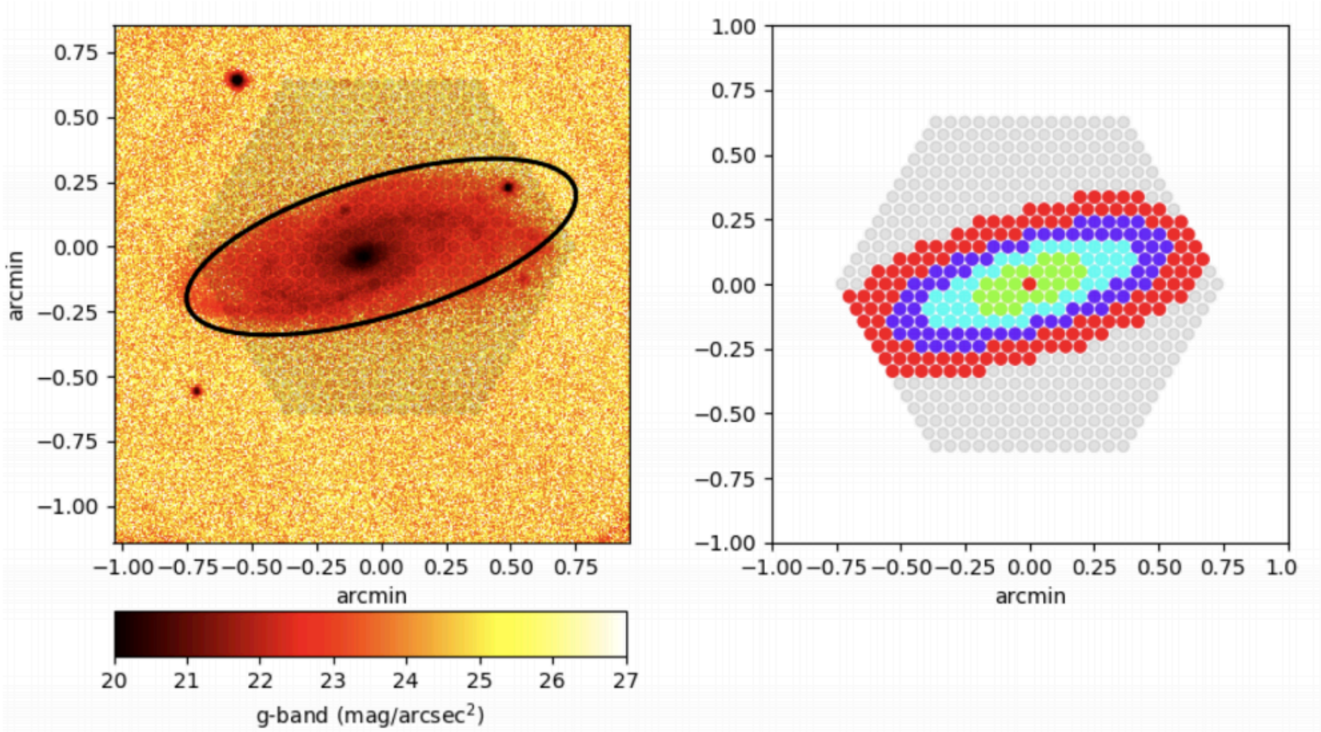
PyAPS.GALAXY MODULE OUTPUT STRUCTURE (MOS mode)

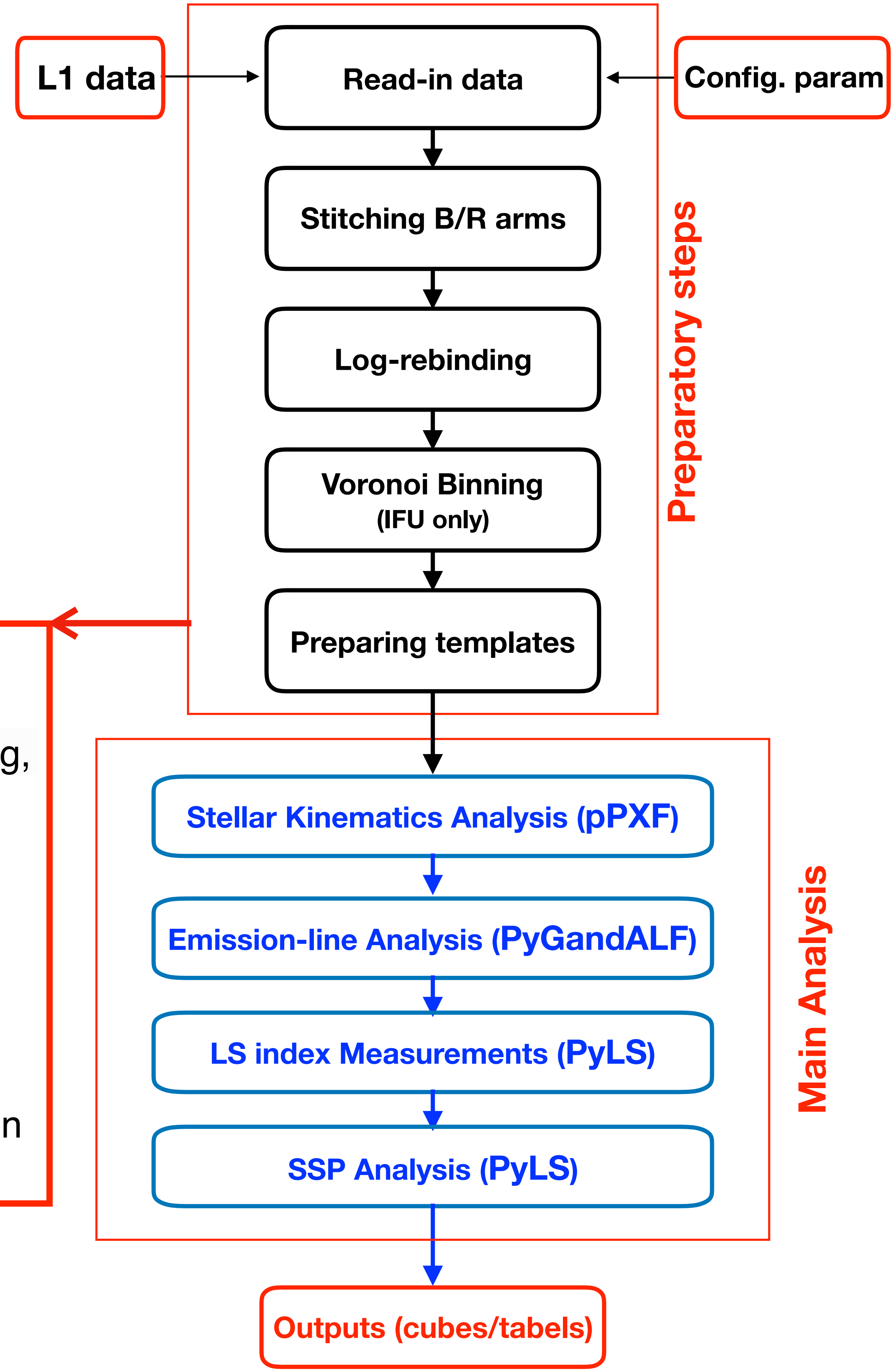
Column	Description
1.VDISP	Velocity dispersion
1.VDISP_ERR	Velocity dispersion error
1.H3	Gauss-Hermite moment h_3
1.H3_ERR	Gauss-Hermite moment h_3 error
1.H4	Gauss-Hermite moment h_4
1.H4_ERR	Gauss-Hermite moment h_4 error
1.VDISPZ	Barycentric redshift for best-fit velocity dispersion.
1.VDISPZ_ERR	Error in VDISPZ.
1.VDISPCHI2	$\chi 2$ for best-fit velocity dispersion
1.LINEZ_X	Redshift of the X line, where X is given as an input parameter (e.g. Ly α, [OII] 372.7nm, Hβ, SII, CN_1, CN_2, Fe4668, etc.)
1.LINEZ_X_ERR	Error in LINEZ_X
1.LINESIGMA_X	Gaussian width of the X line
1.LINESIGMA_X_ERR	Error in LINESIGMA_X
1.LINEAREA_X	Area in Gaussian fit of the X line
1.LINEAREA_X_ERR	Error in LINEAREA_X
1.LINEEW_X	Equivalent width of the X line
1.LINEEW_X_ERR	Error in LINEEW_X



PyAPS.GALAXY (IFU mode)

Stellar and gaseous components kinematics and populations analysis tool





Preparatory steps OUTPUTS:

_table.fits: All necessary information to reconstruct the Voronoi binning, map bins to spaxels and vice versa

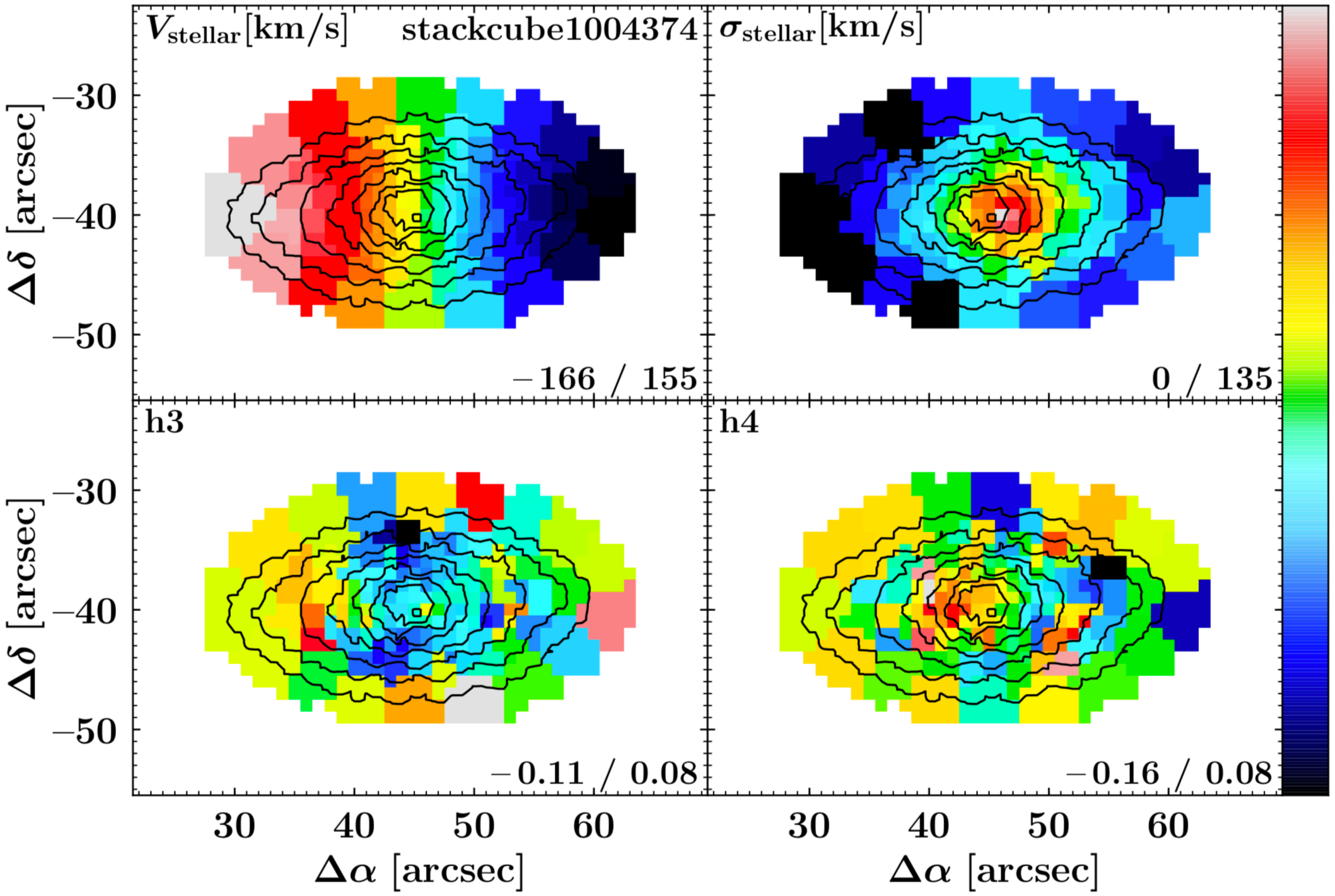
_AllSpectra.fits: The spectrum of each spaxel

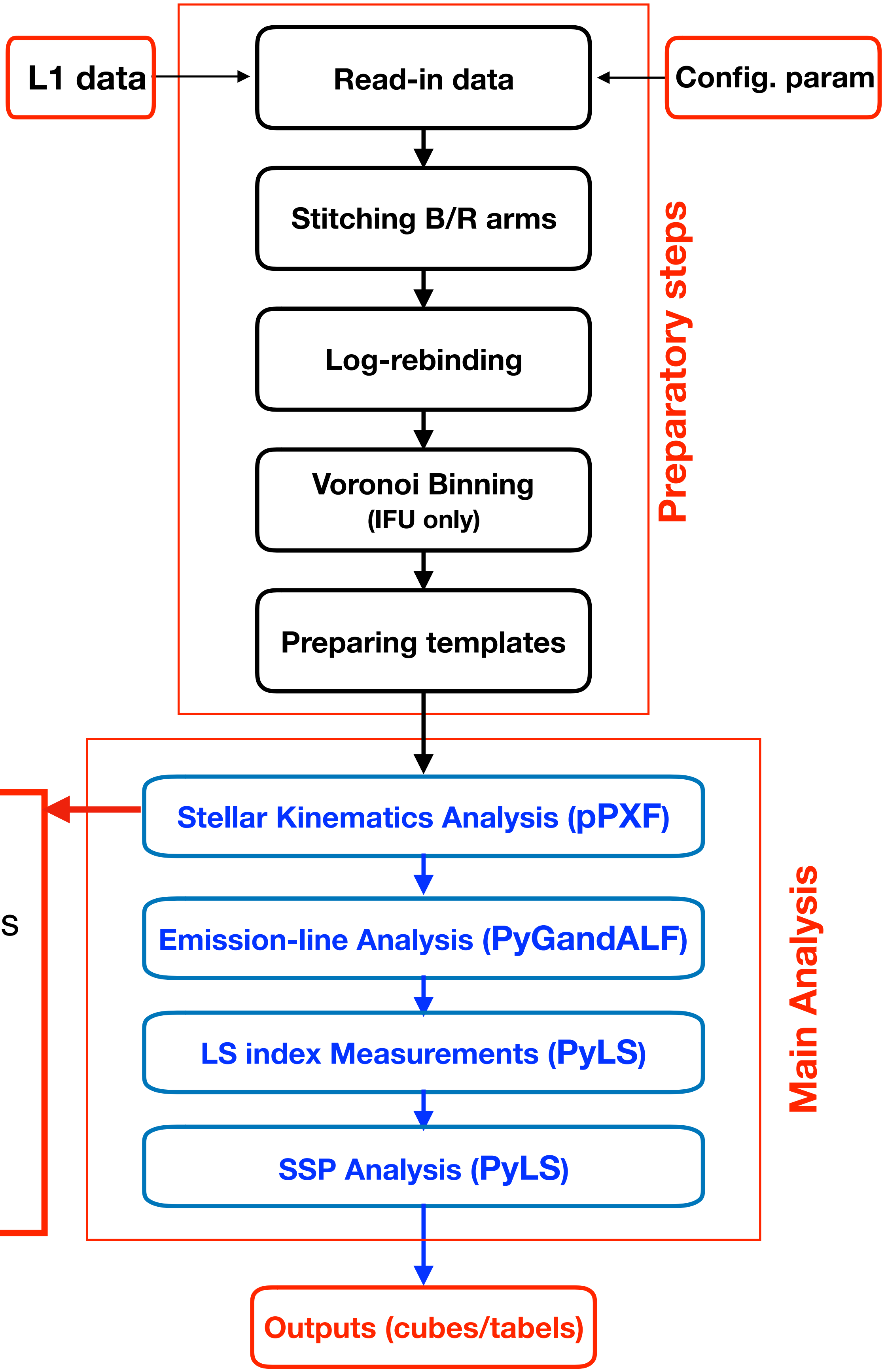
_VorSpectra.fits: The Voronoi-binned spectra equally spaced in velocity domain (logarithmically binned)

_VorSpectra_linear.fits: The Voronoi-binned spectra equally spaced in wavelength domain (linearly binned)

PyAPS.GALAXY (IFU mode)

Stellar and gaseous components kinematics and populations analysis tool





Stellar Kinematics Analysis OUTPUTS:

_ppxf.fits: Results of the extraction of stellar kinematics and their errors

_ppxf-optimalTemplates.fits: Optimal template for the fit on each bin

_ppxf-goodpix.fits: Array of pixels that are not masked during the fit

_ppxf-bestfit.fits: The best fit to the spectrum for each BIN_ID

PyAPS.GALAXY (IFU mode)

Stellar and gaseous components kinematics and populations analysis tool

Emission-line Analysis OUTPUTS:

_gandalf_BIN.fits: The ID of the emission line and Emission line kinematics (Names come in the 2nd extinction)

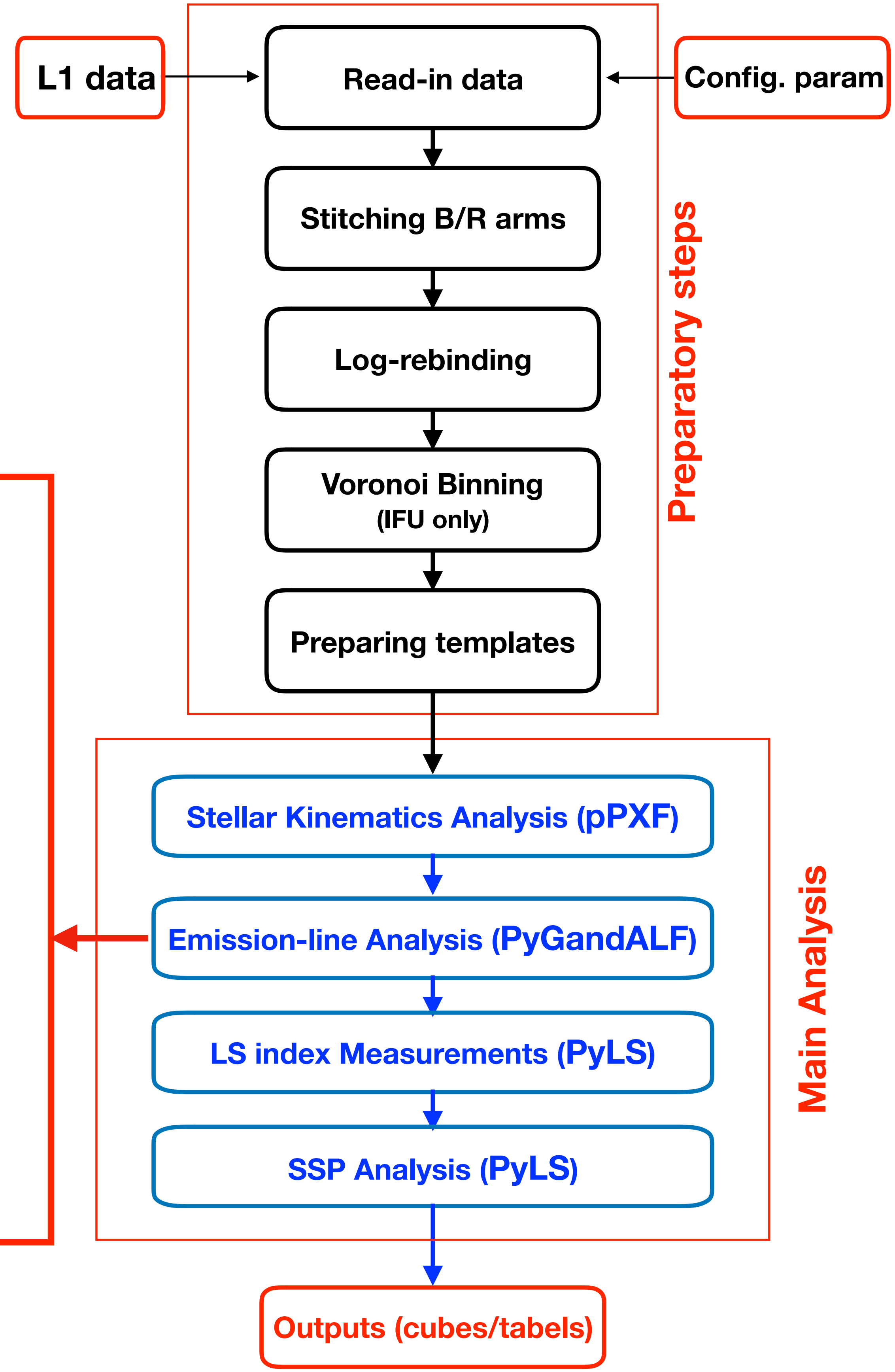
_gandalf-weights_BIN.fits: Normalized weights assigned to each template during the fit

_gandalf-optimalTemplate_BIN.fits: Optimal templates

_gandalf-goodpix_BIN.fits: Pixels that are not masked

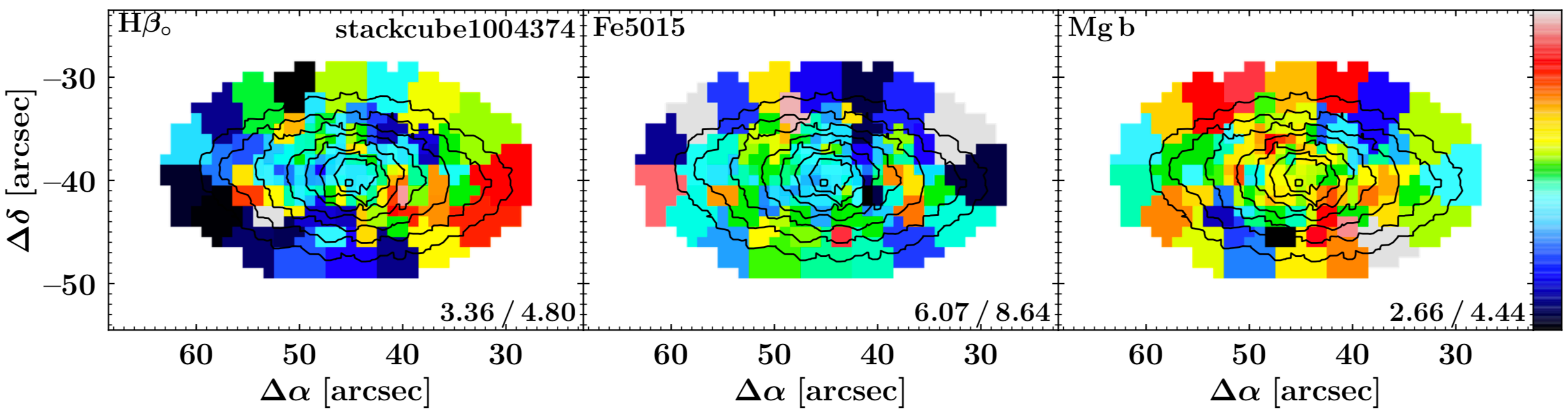
_gandalf-cleaned_BIN.fits: Emission line subtracted spectra

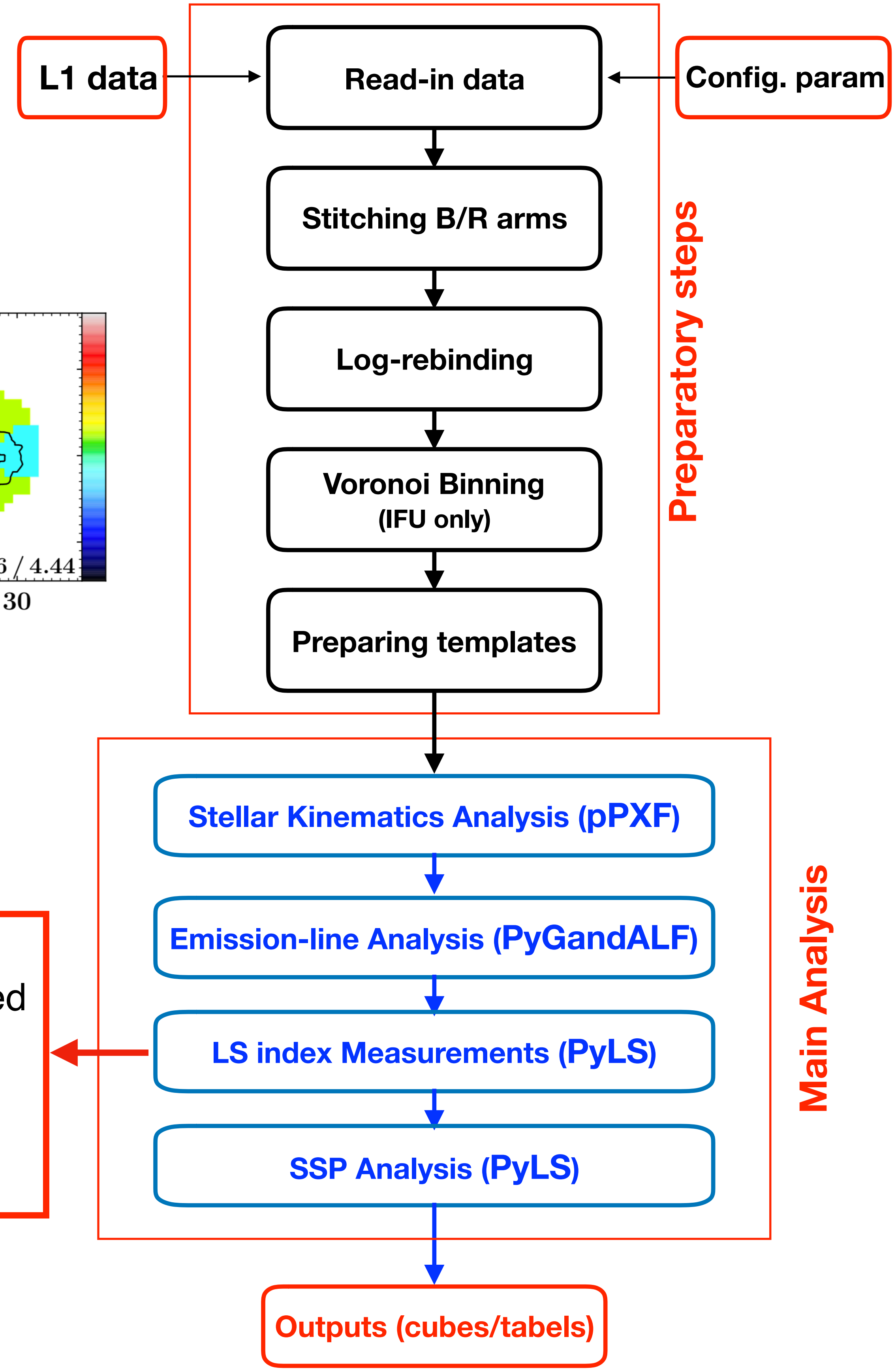
_gandalf-bestfit_BIN.fits: The best fit to the spectrum, including continuum and emission lines



PyAPS.GALAXY (IFU mode)

Stellar and gaseous components kinematics and populations analysis tool





LS index Measurements OUTPUTS:

_ls.fits Extension 1: Line strength indices and their errors as estimated from MC-simulations

_ls.fits Extension 2: Single stellar population equivalent population properties as estimated from the line strength indices

WEAVE-APS contributed softwares

WEAVE Contributed Software is code provided by individual(s) from the WEAVE Survey Consortium that has been incorporated into the APS. The incorporated code runs as part of the APS on WEAVE Survey data, and output of the code is treated as a WEAVE APS product in terms of ingestion by WAS, but will be labelled as CSs when accessed in WAS.

Current list of Contributed Softwares (last update: 16/10/2019)

science team: developer	**(name of) code**	**short description**	**date: status**
WQ: Ignasi Pérez Ràfols	SQUEzE	Redshift determination code.	2019-07: in discussion
SCIP: Roger Wesson	ALFA/NEAT	Physical parameters for nebulae. See: https://www.nebulousresearch.org/codes/alfa https://www.nebulousresearch.org/codes/neat	2019-07: in discussion
GA: Sergey Koposov	RVSEPCFIT RVs from template fitting	Determination of radial velocities from template fitting. The code has been used as part of the Gaia-ESO Survey, and will also be used by DESI. https://github.com/segasai/rvspecfit	2018-11: in APS
GA: David Aguado	FESWI (**FE**rre **S**pectral **WI**ndows)	Derivation of individual chemical abundances for FGK stars. The code assumes stellar parameters from APS (Teff, logg and microturbulence) and re-launches FERRE (over certain ranges of spectra containing the individual lines provided), to derive individual abundances where possible. (Certain aspects of code still under development.)	2019-07: in discussion