Interface request document for the SAS pipeline PLATO-LESIA-PSM-IRD-0004

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1. Introduction

1.1 Purpose of the document

This document details the **input data needed from any external source to the SAS,** allowing for a nominal run of the L1-L2 SAS pipeline; sources being **L0-L1 pipeline, EAS pipeline, the PFU-DB and WP12**. The data are for the target stars of the core program, that is, stars belonging to the P1, P2, P4 and P5 samples. These stars are main-sequence and subgiant stars of spectral type F5 to K7, and M dwarfs. The *WP120 Data Product Definition Document* [RD01] and *Data Flows Document* [RD02] provides full details on the several types of products.

1.2 Scope of the document

This document shall be used as a reference document by WP12. It is part of the *internal* WP120 data package among which the architecture document [PLATO-LESIA-PSPM-DRD-009] and the workflow document [PLATO-LESIA-PSPM-DD-0021]. It will become part of the WP120 data package to be delivered for forthcoming PMC internal reviews and to the PDC. This document is based on the Technical Notes [AD04 to AD..] provided by each WP12X leader.

1.3 Reference documents/applicable documents

[RD01] PLATO-LESIA-PSPM-DRD-0009, Data product description document of the stellar L1/L2 processing pipeline – complete version
[RD02] PLATO-LESIA-PSPM-DD-0021 Work and data flows of the stellar L1/L2 pipeline – Issue 1, rev 7
[RD03] PLATO-LESIA-PSPM-IRD-0001 - Issue 2, rev 1
[RD04] PLATO-UWA-PDC-DD-0001 - Product Definition Document, https://s2e2.cosmos.esa.int/confluence/display/PLATOSGSShare/PLATO-UWA-PDC-DD-0001+-+Product+Definition+Document
[RD05] PLATO-LESIA-PSM-DRD-0011, Data Product Description Document of the Stellar LG Processing Pipelines (MSteSci1 & MSteSci2)
[RD06] PLATO-ICE-PSM-ST-0001, Constants for the stellar analyses pipeline

[AD01] ESA/SPC(2017)33, PLATO Science Management Plan (SMP)
[AD02] PTO-EST-SOC-RS-0247, PLATO Science Implementation Requirements Document (SciRD) issue 2, revision 0
[AD03] PLATO-UWA-PSM-RS-0001, L2 Ground Data Processing User Requirements Document
[AD04] PLATO-UV-PSM-TN-0001_V2, MSAP1: Preparation of analysis-ready light-curves module
[AD05] PLATO-CEA-PSM-TN-0001, KADACS
[AD06] PLATO-AU-PSM-TN-0002, KTremove
[AD07] MSAP1_01_ Transit-like removal-v11-20210215_180220_PG_Gaulme_V4, RER
[AD08] PLATO-ULG-PSM-DD-0035, Description of MSteSci1 and MSAP2 pipelines
[AD09] PLATO-UBI-PSM-DN-0017, MSAP3_01 – Power excess detection test
[AD10] PLATO-UBI-PSM-DN-0018, MSAP3_02 – Large separation detection test
[AD11] PLATO-UBI-PSM-DN-0019, MSAP3_03 – Global asteroseismic parameter & mode identification
[AD12] PLATO-INAF-PSPM-TN-0003, Specification for the baseline algorithm delivery to WP12 Office: Module MSAP4-01
[AD13] PLATO-INAF-PSPM-TN-0005, Specification for the baseline algorithm delivery to WP12 Office: Module MSAP4-03
[AD14] PLATO-AUSAC-PSM-DN-0021, MSAP5-11: Scaling relations: grid-based method

[AD15] PLATO-IA-PSM-DN-0022, MSAP5-12: Scaling relations: direct method
[AD16] PLATO-AUSAC-PSM-DN-0023, MSAP5-13: Grid-based inference: mixed modes
[AD17] PLATO-AUSAC-PSM-DN-0024, MSAP5-14: Grid-based inference: individual frequencies
[AD18] PLATO-AUSAC-PSM-DN-0025, MSAP5-15: Grid-based inference: surface independent
[AD19] PLATO-INAOAC-PSM-DN-0026, Specification for the baseline algorithm delivery to WP12 office: Module MSAP5-21
[AD20] PLATO-IA-PSM-DN-0027, Specification for the baseline algorithm delivery to WP12 office: Module MSAP5-22
[AD21] MSAP5_02- Task 23: Compute M from log_flick + R_phot
[AD22] PLATO-AUSAC-PSM-DN-0028, MSAP5-24: Grid-based modelling: Classical and granulation
[AD23] PLATO-LUPM-PSPM-DN-0010, Description of data products released by WP122100 "1D stellar atmospheres"
[AD24] PLATO-ZAH-PSM-DN-0001, Description of data products released by WP122200 "3D stellar atmospheres"

1.4 List of abbreviations

DO-SAPP	During Operation Stellar Abundances and atmospheric Parameters Pipeline
DP	Data Product
EAS	Exoplanet Analysis System
ESA	European Space Agency
FU	Follow-up
GOP	Ground-based Observation Program
LC	light curve
PLATO	PLAnetary Transits and Oscillations of Stars
PDC	PLATO Data Centre
PDC-DB	PDC-Database
PFU-DB	Preparatory and Follow-Up DataBase
PIC	PLATO Input Catalogue
PMC	PLATO Mission Consortium
ppm	parts per million
PSM	PLATO Science Management
SAS	Stellar Analysis System
SNR	Signal-to-Noise Ratio
TBC	To Be Confirmed
TBD	To Be Defined
TBS	To Be Specified
TBW	To Be Written

2. Definition of the data product types, nomenclature and architecture

2.1 The product types

Product	*Designation*	*Level*
Validated imagettes, light curves, and centroid curves	DP0	L0
Calibrated light curves and centroid curves	DP1	L1

Product	***Designation***	***Level***
Planet transits and parameters	DP2	L2
Asteroseismic mode parameters	DP3	L2
Stellar rotation and activity	DP4	L2
Stellar radii, masses, and ages	DP5	L2

Table 2: Data Products

2.2 Overall SAS pipeline

The SAS pipeline is designed as specified in the architecture document [RD01]. We recall that it is composed of five main modules defined as follows:

- MSAP1: *Preparation of analysis-ready light-curves*
- MSAP2: *Classical stellar parameters determination* (includes DO-SAPP)
- MSAP3: *Stellar oscillation modes detection and measurement* (this module provides DP3)
- MSAP4: *Stellar rotation and activity measurement* (this module provides DP4)
- MSAP5: *Stellar properties determination* (this module provides DP5)

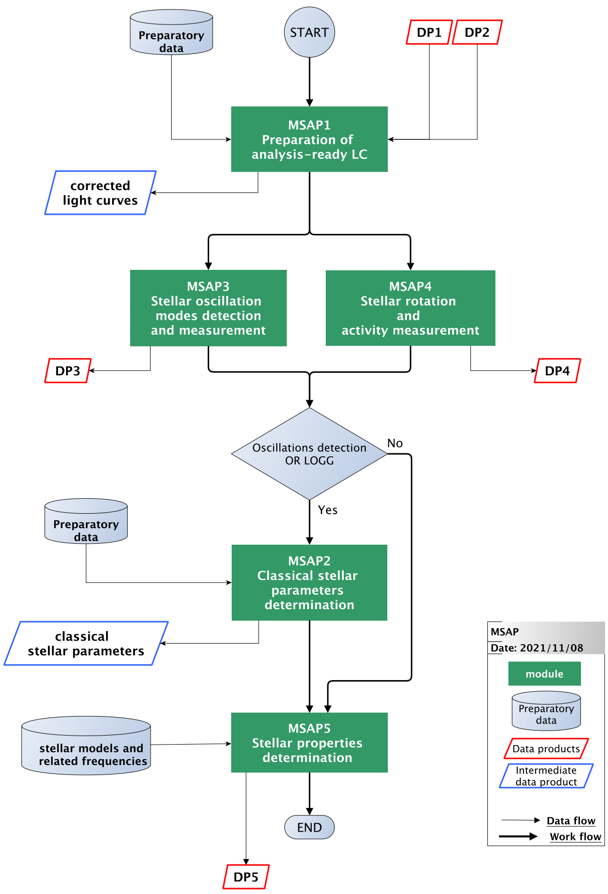

Figure 1: Work and data flow of the SAS L1/L2 pipeline

3. Definition of the data product content

3.1 Data needed from L0-L1

For the stellar L1-L2 processing pipeline (a.k.a. SAS) to start properly, calibrated light curves (LC) are the main input needed.
These LC should be delivered in the form of one concatenated time series for all quarters, the unit being ppm versus BJD. The flux doesn't necessarily need to be normalized. In any case, the normalization should be specified in the metadata.
Along with the LC, two arrays assigning at each timestamp its quarter of observation and a flag for gaps in the light curve should be provided.
Additionally, the metadata section should also be fed with basic information on the LC such as its cadence, its length of observation (in BJD), the duty cycle and flux dilution.

Product	***Designation***
Calibrated light curves, with quarters and gaps information	DP1
Metadata of LC, including norm status, length, cadence of observation, duty cycle, flux dilution	DP1_metadata

Table 3: Data needed from L0-L1

3.2 Data needed from EAS pipeline

For the first module of the SAS (MSAP1) to remove transits in the LC, multiple methods were developed. Among these methods, some require information on the transiting body, which can be extracted from the EAS pipeline according to documentation on Confluence under *PDD_L2_IDP Transit Removal Kit*.

The most important/needed IDP is Detection, under "PDD_L2_IDP EAS Quality-control-metrics per target" (previously IDP_EAS_QC_TARGET_TCE_DETECTION), as it's the one that will allow the SAS pipeline to decide whether it should wait for more information on the transit(s) coming from the EAS pipeline, or not.

Then, as the most straightforward and accurate method should be to remove the transit according to the transit model provided by the EAS, the next DP needed is contained in the Transit Removal Kit (TRK) and is in the table Relative Flux Curve: flux. The content of this IDP being a time series of coefficient to divide the LC in order to obtain a cleaned LC.

We also need information on each transit if, for any reason, the transits have not been removed after the transit model removal method.

The information being:

- the transit period(s) of the body(/ies),
- the timestamp(s) of the middle point(s) (maxima) in transit(s),
- the width(s) of the transit(s),

For all the parameters above, the unit is expected to be in BJD. They are all present in EAS Transit Removal Kit under various tables (see Table 4 in this document for a summary).

Finally, a time series containing flags to indicate if a point is in a transit (flag=1) or not (flag=0) should be included. This information doesn't seem to exist for now under the EAS TRK section but can be easily extracted from the transit model.

Product	*Source*	*Type, Dimension*	*Unit*
Detection(s)	EAS Quality-control-metrics per target, detection (TBC)	Boolean, 0	N/A
Transit model(s)	EAS TRK, Relative Flux Curve, flux	Float, 1 (Length of LC)	dex
Transit period(s)	EAS TRK, TCE, period	Float, 1 (Number of period)	BJD
Transit timestamp(s)	EAS TRK, Eclipse table, t0	Float, 1 (Number of period)	BJD
Transit width(s)	EAS TRK, Eclipse table, as a combination of t1 & t2	Float, 1 (Number of period)	BJD
Flags	EAS (eventually from transit model)	Float, 1 (Length of LC)	N/A

Table 4: Data needed from the EAS pipeline

For all the sources above, information has been gathered from the EAS section of the PDD of confluence, based on the parameter's definition. As the EAS is also delivering these kinds of information under their DP2, an issue has been raised.

3.3 Data needed from the PFU-DB

Many parameters are required from the PFU-DB in the SAS pipeline. While most of them comes from the MSteSci pipelines, the complete list is present in Tables 5 and 6 bellow.

The MsteSci1 & 2 modules will primarily operate before launch, and then each time new Lg data is aquired.

The MSteSci1 module will compute the classical stellar parameters (e.g. Teff, [Fe/H]) of all the PLATO core program targets.

The MSteSci2 module will compute stellar properties (e.g. radius, mass and age) based on classical (i.e. non-seismic) methods.

Product	*Description*	*Type, Dimension*	*Unit*
IDP_PFU_TEFF_SAPP	Value of Teff selected after statistical analysis: combination of values yielded from the SAPP pipeline, after validation by WP125200	Float, 1	K
IDP_PFU_LOGG_SAPP	Value of log g selected after statistical analysis: combination of values yielded from the SAPP pipeline	Float, 1	dex

Product	Description	Type, Dimension	Unit
IDP_PFU_[FE_H]_SAPP	Iron over hydrogen abundance ratio by number relative to the solar value	Float, 1	dex
IDP_PFU_COVMAT_SAPP	Covariance matrix for classical parameters from the SAPP pipeline	Float, 2	N/A
IDP_PFU_RADIUS_SAPP	Stellar radius combined by MSetSci1 from various methods	Float, 1	$R_\odot$
IDP_PFU_[ALPHA_FE]_SAPP	Mean abundance ratio by number of the α elements over iron relative to the solar value	Float, 1	dex
IDP_PFU_[ALPHA_FE]_ SPECTROSCOPY	Alpha elements abundances relative to iron from spectroscopy	Float, 1	dex
IDP_PFU_VSINI_SPECTROSCOPY	Projected rotational velocity from spectroscopy (only for spectral synthesis)	Float, 1	km/s
IDP_PFU_[ELEM1_ELEM2]_ SPECTROSCOPY	Chemical abundance of element1 (TBD) relative to element2 (TBD) from spectroscopy	Float, 2	dex
LG_PFU_OBS_DATA	Contains Gaia BP-RP spectrophotometry from final release and Spectra as described in the PDD (under PFU Observed spectrum)	Float, 1 (BP-RP) str, 1 (Spectra files)	mag N/A
IDP_PFU_LOGG_PHOTOMETRY	Photometric surface gravity	Float, 1	dex
IDP_PFU_TEFF_PHOTOMETRY	Effective temperature from photometry	Float, 1	K
IDP_PFU_METADATA_ PHOTOMETRY	Metadata of the photometry	N/A	N/A
IDP_PFU_EXTINCTION	Interstellar extinction	Float, 1	
IDP_PFU_L_IRFM	Luminosity from infrared flux method (IRFM)	Float, 1	$L_\odot$
IDP_PFU_THETA_IRFM	Angular diameter from IRFM	Float, 1	
IDP_PFU_TEFF_IRFM	Effective temperature from IRFM	Float, 1	K
IDP_PFU_RADIUS_IRFM	Radius from IRFM	Float, 1	$R_\odot$
IDP_PFU_METADATA_IRFM	Metadata of the IRFM	N/A	N/A
IDP_PFU_TEFF_SBCR	Limb-darkened effective temperature from surface brightness relations	Float, 1	K
IDP_PFU_THETA_SBCR	Limb-darkened angular diameter from surface brightness relations	Float, 1	

Product	*Description*	*Type, Dimension*	*Unit*
IDP_PFU_RADIUS_SBCR	Limb-darkened radius from surface brightness relations	Float, 1	R⊙
IDP_PFU_METADATA_SBCR	Metadata of the SBCR	N/A	N/A
IDP_PFU_LD_ INTERFEROMETRY	Limb-darkened coefficients from interferometry	Float, 1	
IDP_PFU_THETA_ INTERFEROMETRY	Limb-darkened angular diameter from interferometry	Float, 1	K
IDP_PFU_TEFF_ INTERFEROMETRY	Limb-darkened effective temperature from interferometry	Float, 1	K
IDP_PFU_RADIUS_ INTERFEROMETRY	Limb-darkened radius from interferometry	Float, 1	R⊙
IDP_PFU_METADATA_ INTERFEROMETRY	Metadata for the interferometry	N/A	N/A

Table 5: Data needed from MSteSci1

Product	*Description*	*Type, Dimension*	*Unit*
IDP_PFU_MASS_CLASSICAL	Mass determined from classical methods (non seismic)	Float, 1	M⊙
IDP_PFU_RADIUS_CLASSICAL	Radius determined from classical methods (non seismic)	Float, 1	R⊙
IDP_PFU_AGE_CLASSICAL	Age determined from classical methods (non seismic)	Float, 1	Myr
IDP_PFU_METADATA_CLASSICAL	Metadata of the production of the classical parameters, allowing to retrieve mass_classical, radius_classical, age_classical from the outputs of MSteSci1	N/A	N/A

Table 6: Data needed from MSteSci2

3.4 Theoretical input data needed from WP12

The SAS pipeline will also require input data of theoretical type. In particular the seismic and non-seismic determination of stellar properties (performed in MSAP5) rely on stellar models optimization. Similarly, the determination of stellar atmospheric parameters requires stellar atmospheric models.

Hence, we foresee the use of grids of stellar models, containing: stellar evolution tracks, stellar models internal structures, and stellar models oscillation spectra. Concerning stellar atmosphere models, they will come in two flavors: 1D or 3D.

While the provision of such theoretical data is under the responsibility of WP120 (WP121 for the grids of stellar models and relative structures and oscillations, and WP122100 for the 1D stellar atmospheres, and WP122200 for the 3D ones), they are delivered either to the PDC-DB directly (for the stellar model grids TBC), either to the PFU-DB (for the stellar atmosphere grids). As such, they are considered as intermediate products from the point of view of SAS.

Product	***Description***	***Type***
PDP_WP12_MOD_STRUCTURE	Stellar internal structure models	Table
PDP_WP12_MOD_OSC_FREQ	Stellar oscillations grids: For all models in PDP_B_SAS_MOD-EVOL, adiabatic frequencies will be provided for low angular degree, l=0, 1, 2, 3, modes.	Table
PDP_WP12_MOD_EVOL	Stellar evolution tracks. They contain: mass, age, Teff, L, radius, surface chemical composition, central temperature, density, boundary of convective envelopes (both in radius and mass), surface rotation velocity (if rotation is included in the calculations)	Table

Table 7: Data needed from WP121

Product	***Description***	***Type***
PDP_WP12_MOD_STELLAR_SPECTRA_1D	Synthetic spectra from 1D models: LTE and non-LTE synthetic spectra, fluxes and intensities from 1D stellar atmospheres models. 1D MARCS theoretical synthetic spectra computed by WP122100.	Table
PDP_WP12_MOD_STELLAR_SPECTRA_3D	Synthetic spectra from 3D models: LTE and non-LTE synthetic spectra, fluxes and intensities from 3D stellar atmospheres models. 3D STAGGER theoretical synthetic spectra computed by WP122200.	Table
Metadata	Metadata containing the config file of the spectra (in case want to re-generate them)	N/A

Table 8: Data needed from WP122

4. Pending issues and questions

This document is meant to be updated regularly. At the present state, some issues have been pointed out which need to be resolved.

[WP12IRD_I01] Transit model for each body? For all?

[WP12IRD_I02] Transit model, period, timestamp and duration of transits should come from DP2 or from Transit_removal_kit?

[WP12IRD_I03] Upon positive transit flag (TCE), if we don't immediately have the DP2, do we wait for them or do we proceed without, redoing the transit removal later on if asked for a specific star?

[WP12IRD_I04] Depending on the needs of EAS pipeline, an interface may arise regarding model grids.

[WP12IRD_I05] Content of PFU-DB requirements could change depending on discussion's outcomes with the group in charge.

[WP12IRD_I06] Is the parameter IDP_PFU_[ALPHA_FE]_SPECTROSCOPY really needed? Can't we use the SAPP equivalent instead? TBC by MSAP5-1