README PHANGS-MUSE Data Release 2.2

**April 2022**

*This is a minor revision of the second major release of the MUSE-PHANGS datasets*. *This is the first new release after the MUSE public data release, which corresponds to internal DR2.1.*

It includes the products of the MUSE-PHANGS data reduction pipeline (<https://github.com/emsellem/pymusepipe>) and of the MUSE-PHANGS data analysis pipeline (<https://gitlab.com/francbelf/ifu-pipeline>).

The data reduction and analysis workflow are described in detail in the MUSE Survey Paper, or MSP, [Emsellem et al. 2021](https://ui.adsabs.harvard.edu/abs/2021arXiv211003708E/abstract).

We welcome feedback: please write to us using the MUSE mailing list ([muse@phangs.groups.io](mailto:muse@phangs.groups.io)) or the slack channel (#muse\_general).

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# Major Changes (DR2.1 -> DR2.2):

* **DRP Bug fixes:** the copt datacubes for NGC1365, NGC1672, NGC3351 were affected by a bug caused by incorrectly double counting exposure after masking satellite trails in pymusepipe.
* **DAP bug fixes**:
  + A bug in the implementation of the extinction in the stellar population module was fixed. This bug affects the stellar populations derived from all previous data releases. The main effects of this bug on the DR<2.1 data are described below:
    - mass is preferentially higher in the dust/gas lanes, not much change in disk globally (generally below 0.1 dex, but reaching up to 0.2 dex)
    - age is significantly lower in regions of high star formation, not much changed elsewhere
    - metallicity is mostly varying in regions of high star formation, not much change elsewhere
  + A bug was fixed in reading the M/L ratios. This only has a small effect on the light-weighted quantities and a small (0.03 dex) effect on masses.
  + In the copt analysis three galaxies (NGC 4321, NGC1385, NGC 1566) were run by mistake with a target S/N =35 instead of 100. This is now fixed.
* **Starmasks**: Starmasks for the 15asec data are generated based on the same list of sources used in DR2.1. Starmasks for the other levels have not been changed.
* **Matched physical resolution cubes/maps**: We release for the first time cubes and maps at 15’’ (2.4’’ spaxels) and 150pc resolution (with 0.2’’ spaxels for all galaxies).

# Content

1. **Native**: the *native* mosaics are composed of individual exposures which had their PSF characteristics left untouched. The PSF therefore varies with position (mostly from pointing to pointing) and wavelength. The data has the native spatial sampling (spaxel/pixel) of 0.2’’. These data are under the **native** folder.
2. **Convolved**: each individual datacube has been convolved using a target Gaussian PSF with a certain width, provided in the name (e.g., \_0.93asec). The goal for these datacubes is to have a PSF which is constant all over the mosaic field of view (all spaxels) andacross the whole wavelength range. For this release we provide:
   1. **copt** = optimised convolution, hence the best PSF for the full mosaic of that target. The PSF FWHM is indicated in the name of each “MAPS” or CUBE or IMAGE (in arcsec). The spatial sampling is still that of the original data (0.2’’). For this data release, an extra run of the DAP with additional stellar population templates was performed for this dataset.
   2. **150pc** = means the convolution was performed to homogenise the PSF to 150pc using the distances from the sample table. The spatial sampling is still that of the original data (0.2’’).
   3. **15asec**= same, but for a fixed scale of 15 arcsec, chosen to match the coarsest matched resolution of the z0mgs products. The spatial sampling is 2.4’’.

Under each of the **native, copt, 150pc, 15asec** folder you can find:

1. The **datacubes** folder containing:
   * the final MOSAIC datacubes (<TARGETNAME>.fits), where <TARGETNAME> is composed of <GALAXY\_NAME>-<RESOLUTION> for the convolved products.
2. The **filterImages** folder containing :
   * the reconstructed images of the MOSAICS in various bands following the same naming convention as in the datacubes folder, except the name of the filter is appended to <TARGETNAME> so the files are name <TARGETNAME>\_<FILTER\_NAME>.fits. FilterImages are only provided for native and copt.
3. The **MUSEDAP** folder containing:
   * Individual fits files (one per galaxy) including all the derived maps as extensions. Examples of the extension names and content are given in the MSP. In the case of the copt data the MUSEDAP folder contains two folders, **fiducial** and **young\_templates**, corresponding to different runs on the DAP on that dataset. The difference is described below.
4. **Starmasks**: a set of 2D images representing star masks, based on Gaia DR2. Under this folder you can find starmasks for the 0.2’’ sampling (native, copt, 150pc) and 15asec data (with 2.4’’ sampling). The starmasks for native and copt are identical to each other and are also identical to those released in DR2.1.

# CUBES AND IMAGES

* **DATACUBES** [FITS-files]
  + These contain all the 3D information needed to reconstruct images and spectra. Each datacube contains several extensions:
    - A PRIMARY extension with a detailed header. It mentions when the data were taken and some general information about the instrument. The name of the target is found under the KEYWORD “OBJECT”.
    - DATA: a 3D array, containing the datacube.
    - STAT: a 3D array, with the same size as DATA. It provides the VARIANCE per spaxel. These are the values estimated by the pipeline and should only be used as indicative.
* Reconstructed **IMAGES** [FITS-files]
  + Each image contains, in its name, the filter it corresponds to. It was built using the associated MUSE cube, and the transmission curve of that filter.

# ANALYSIS Datasets

The Data Analysis Process (**DAP**) Datasets are made of FITS-Files with a large number (> 100!) of extensions, each of which is either a FITS Table or an Image.

Extensions of these “**MAPS**” files include:

* A PRIMARY hdu with a simple header containing the spectral range used for the analysis (LMIN, LMAX), the systemic velocity used for the analysis (called “REDSHIFT”), and a few other parameters such as the S/N used for the Voronoi binning (TARGET\_SNR).
* A number of extensions (ImageHDU) mapping a certain quantity. The full list is available in the MSP, table 1. This has the stellar kinematics, stellar populations, star formation history, extinction information, with associated formal uncertainties.
* The full list of extensions and their units is given at the bottom of the present document.

# WARNINGs: limitations, coming upgrades

## AO Mode

Some Raman scattered lines can be part of the spectrum. The two brightest are: O2 6484.39, N2 6827.17. Please consider masking these regions when using the spectra (this is NOT a high redshift object).

## Astrometry

No changes with respect to the public data release. Individual exposures have been aligned and rotated following a process which compares the MUSE datacube to the available WFI broad-band images which have themselves been calibrated via the DR2 Gaia stellar catalogs. Alignment is performed semi-automatically by humans. A new automatic alignment module is being developed for future releases.

## Noise and Variance

The variance in the datacubes is the result of the ESOREX pipeline, taking into account the relative weighting of each individual exposure, and after a relatively complex drizzling process. It, however, does not account for cross- (non-diagonal) terms. It is a good estimate of the variance per spaxel but generally slightly (~20%) underestimates certain systematics***.*** See MSP section 6.2.1.

## Reconstructed Images

Beware that reconstructed images are using a set of given filters, but that **these filters may not be entirely included in the MUSE spectral domain** (or in other words, that there may be missing data within the relevant filter spectral range). The AO gap is interpolated over when computing the images, with a linear dependence on wavelength (straight line connecting the low and high boundaries).

## Errors in the convolved cubes

Because of the convolution process necessary to derive the convolved dataproducts, the errors for individual spaxels are strongly correlated. If you treat the spaxel errors as independent (e.g. by extracting the spectrum within an aperture) the error on the extracted spectrum is not the quadrature sum of the errors of the individual spaxels you have summed. Recipes for summing the errors of correlated data will be provided in a future update to the MSP.

## Analysis dataproducts: stellar kinematics and emission lines

Analysis dataproducts related to stellar kinematics (v and sigma) and gas emission lines are considered reliable.

Users are also asked to keep in mind a series of warnings:

1. The spectral resolution of MUSE is wavelength-dependent and goes from 80 km/s at Hb to 50 km/s at Ha. Velocity dispersions of emission lines are typically much narrower than the spectral resolution of the instrument (in particular velocity dispersions of most HII regions are unresolved).
2. The wavelength range redder than 7000\AA is not fitted in this data release, mostly due to the large amount of sky residuals. We therefore do not provide fluxes for lines redder than 7000\AA (e.g. [SIII]9068).
3. We note that the stellar kinematics are computed on (Voronoi) binned spectra and NOT on individual spaxels. Users comparing gas and stellar kinematics will want to take the different binning into account.

**Analysis dataproducts: binning**

A set of different approaches have been taken in this data release with regards to binning, which is used for the stellar population and stellar kinematics analysis (but NOT for the emission lines)

* The native resolution data is binned using Voronoi binning and a S/N target of 35.
* The copt resolution data is binned using Voronoi binning and a S/N target of 100. NOTE that this S/N target is set in a way that does not consider covariance, in other words it leads to spectra that have a S/N similar to that of the native binning (S/N = 35) when taking into account the fact that the spaxels are covariant in the copt cubes.
* In the 150pc resolution data the binning scheme is imposed to be the same as that of the native cubes, in order to avoid having to compute the effect of covariance for each galaxy, which is convolved with a distance-dependent kernel.
* In the 15asec cubes, no binning is performed because the S/N is always high enough for our purposes in the 2.4’’ spaxels.

**Analysis dataproducts: stellar population properties**

The stellar population maps (age and metallicity of the stars, stellar extinction) are affected by the same noticeable pointing-to-pointing jumps already documented in the MSP Sec 6.2.1, in particular in the stellar extinction maps.

The SSP models used for the spectral fitting are the same as in the public data release in all the MUSEDAP folders, except in the copt **young\_templates** subfolder. This contains the analysis run using a new set of templates, described blow:

MILES extension to younger ages, presented in Asa'd et al. (2017).

- Padova Isochrone.

- 18 Age bins [6.3 Myr to 14.12 Gyr]

- four [Z/H] bins:

- For templates older than 63 Myr: [Z/H]= -0.7, -0.4, 0, 0.22

- For templates younger than 63 Myr: [Z/H] =-0.7, -0.4, 0, 0.41

- Note that the lowest-metallicity templates ( [Z/H] =-1.33) were removed from the grid.

## Masking stars

Foreground stars have not been masked in any of the MUSE cubes or product maps. A set of star masks is released to allow for post-facto masking.

# Columns in the MAPS files

Here is the detail of which columns are included in the MAPS file. The first number is the extension number you need to use to access it.

**With python:**

from astropy.io import fits as pyfits

maps = pyfits.open(“NGCXXX….maps.fits”)

maps.info() # will provide you with the list of extension

maps[ext\_number] # will give you access to the ext\_number (or ext\_name) extension

maps[ext\_number].data # will give you access to the associated data array

***#Ext\_number EXTNAME BUNIT***

#001 = ID

#002 = FLUX - 1e-20 erg/s/cm2/AA/spaxel

#003 = SNR

#004 = SNRBIN

#005 = BIN\_ID

#006 = V\_STARS - km/s

#007 = FORM\_ERR\_V\_STARS - km/s

#008 = SIGMA\_STARS - km/s

#009 = FORM\_ERR\_SIGMA\_STARS - km/s

#010 = H3\_STARS

#011 = FORM\_ERR\_H3\_STARS

#012 = H4\_STARS

#013 = FORM\_ERR\_H4\_STARS

#014 = BIN\_ID\_LINES - 1e-20 erg/s/cm2/spaxel

#015 = V\_STARS2 - km/s

#016 = SIGMA\_STARS2 - km/s

#017 = CHI2\_TOT

#018 = HB4861\_FLUX - 1e-20 erg/s/cm2/spaxel

#019 = HB4861\_FLUX\_ERR - 1e-20 erg/s/cm2/spaxel

#020 = HB4861\_VEL - km/s

#021 = HB4861\_VEL\_ERR - km/s

#022 = HB4861\_SIGMA - km/s

#023 = HB4861\_SIGMA\_ERR - km/s

#024 = HB4861\_SIGMA\_CORR - km/s

#025 = OIII4958\_FLUX - 1e-20 erg/s/cm2/spaxel

#026 = OIII4958\_FLUX\_ERR - 1e-20 erg/s/cm2/spaxel

#027 = OIII4958\_VEL - km/s

#028 = OIII4958\_VEL\_ERR - km/s

#029 = OIII4958\_SIGMA - km/s

#030 = OIII4958\_SIGMA\_ERR - km/s

#031 = OIII4958\_SIGMA\_CORR - km/s

etc for the other lines

#123 = STELLAR\_MASS\_DENSITY - M\_sun/pc2

#124 = STELLAR\_MASS\_DENSITY\_ERR - M\_sun/pc2

#125 = AGE\_MW - log(Age/yr), mass weighted

#126 = AGE\_MW\_ERR - log(Age/yr) dex, mass weighted

#127 = Z\_MW - [Z/H] dex, mass weighted

#128 = Z\_MW\_ERR - dex, mass weighted

#129 = AGE\_LW - log(Age/yr), light weighted

#130 = AGE\_LW\_ERR - log(Age/yr) dex, light weighted

#131 = Z\_LW - [Z/H] dex, light weighted

#132 = Z\_LW\_ERR - dex, light weighted

#133 = EBV\_STARS - mag

Of course the units of velocity and velocity dispersion for emission lines ought to be km/s.

More physical description of columns (taken from the survey paper):

