MYOSOTIS User Guide

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January 18, 2019

1 Introduction

Make Your Own Synthetic ObservaTIonS (MYOSOTIS)

This code creates synthetic imaging and spectroscopic data of space and ground-based telescopes as well as custom (user-defined) instruments within any FOV. The stellar and interstellar medium information (position, mass, velocity, metallicity, age, gas density) should be provided by the user. The user can choose different filters from a list of provided filters or define a new filter, to suit the observational instrument that they want to mimic (see `http://svo2.cab.inta-csic.es/theory/fps/`). Knowing the age and mass of the stars, their stellar parameters (T_{eff}, logg and logL) are estimated using PARSEC evolutionary models. Knowing the stellar parameters, a proper SED will be selected for each star, and finally stellar fluxes are estimated within a given filter using that SED. If there is an extinction, then A_λ is estimated (using `EXTmodels`) in each wavelength channel. User can always update the library of the Evolutionary and atmosphere models. Even for each input star, User can user her/his own SEDs.

The observing conditions, i.e. seeing, Strehl-Ratio (SR), detector's pixel scale of a given instrument, FOV, observer's line-of-sight and finally the angular resolution of the telescope can be defined in MYOSOTIS. Since most of the instruments can not achieve their theoretical optimum resolution ($\sim \lambda$/Diameter), the user can also define their own resolution. The estimated flux of stellar sources spreads on the detector using a 2D point spread function (PSF) whose full width at half maximum (FWHM) is equal to the resolution. The user can choose a Gaussian distribution or an Airy pattern for the PSF of stellar sources. The extinction can be applied on the output data, knowing the column density of the gas in front of each source.

This extinction could be uniform, patchy, or taken from a full 3D smoothed particle hydrodynamics (SPH) simulation data.

2 Input parameters

- `Project-name` : Name of the project chosen by the user
- `filestar` : name of the file contains 10 columns of stellar sources information:

  X[pc], Y[pc], Z[pc], Vx[km/s], Vy[km/s], Vz[km/s], Mass[$M_\odot$], Logage[yr], Metallicity, gasdensity[$M_\odot/pc^2$]

  This file contains 3D position and velocity of stars (first 6 columns) and their mass, Log(age), metallicity and gas column density in front of each star (columns 7 to 10 respectively). This file can be produced from the result of N-body simulations of star clusters or manually by the user. There is no limitation for the number of stars. The stars can have different ages or metallicities which is useful specifically for the simulation of clusters with different populations. Zero values can be put for the velocities and gas density in front of each star, If user do not have any information about them. The Doppler effect will NOT be applied if the velocities have zero values. If gas density (column 10) has zero values, then it means there is no extinction in the line-of-sight of the observer unless the information of the gas is provided in `filecloud` (see next output).

- `filecloud` : name of the file contains 8 columns of the cloud's information:

  X[pc], Y[pc], Z[pc], Vx[km/s], Vy[km/s], Vz[km/s], Mass[$M_\odot$], smoothing-length[pc]

  This file contains cloud particle's 3D position and velocity (columns 1 to 6) and the particle mass and smoothing length (column 7 and 8), which are the typical output of the SPH simulations. If user do not have information about the gas cloud from SPH simulations, they can simply use `Columndensities='user'` and use the column density values in the last column of `filestar` .

- `Columndensities`: column density of the gas cloud in front of stars.

'sph': reads it from the `filecloud` (provided by the SPH simulations)

'user': reads it from the `filestar`, last column in the unit of $[M_\odot/pc^2]$

If there is no extinction in the simulations, user should set `Columndensities= 'user'` and put Zero values in the last column of `filestar`.

- `filter` : name of the instrument's filter which contains 2 columns of:

  Lambda[A], filter-transparency

  User can choose any filter from the provided list of filters or can define her/his own filter. Full list of provided filters are shown in Appendix A. For example if user wants to use the first filter in the list (2MASS/H) she/he should set `filter='Filters/2mass/2MASS-2MASS.H.dat'`

- `distance` : distance of the center of the simulation [X=0,Y=0,Z=0] from the observer [pc].
  Note that the X,Y,Z positions in the `filestar` and `filecloud` are respect to the center of the simulation. So the final distance of each star will be calculated by adding `distance` plus their distance from the center (in the line-of-sight of the observer). So even if all the stars have the same intrinsic flux, in the synthetic image they will not have the same flux since they have different locations from the center-of-simulation.

- `EXTmodel` : model to be used for estimating extinction in different wavelengths (A_λ).
  'Fmodel': The code uses a function to calculate extinction in a given wavelength knowing optical extinction values (A_V and R_V). This function uses the average extinction curve in the optical-through-IR range (0.125 - 3.333 μm) which is reproduced with a cubic spline and a set of anchor points from Fitzpatrick (1999).
  'Dmodel': The code uses synthetic extinction curves [1] from Draine (2003a,b,c); Li & Draine (2001); Weingartner & Draine (2001). Extinction, absorption, albedo, $< \cos(\theta) >$, and $< \cos^2(\theta) >$ have been calculated for wavelengths from 1 cm (30 GHz) to 1 Angstrom (12.4 keV), for selected mixtures of carbonaceous grains and amorphous silicate grains. These models cover three values of R_V, 3.1, 4.0 and 5.5.

[1]`www.astro.princeton.edu/~draine/dust/dustmix.html`

- `Rv` : Av/E(B-V) constant value, for example should be set to 3.1 for MW Galaxy. If user chooses `EXTmoel='Fmodel'` then any value can be chosen for Rv, but for the `EXTmoel='Dmodel'` user is limited to choose Rv of 3.1, 4.0 and 5.5 only.

- `res` : pixel sampling of the instrument [arcsecond/pix]

- `fovx`, `fovy` : Field of view in x and y [arcsecond]

- `fwhm` : angular resolution of the observational instrument [arcsecond]. The optimum resolution for a single dish telescope is about λ/D. If the telescope does not have adaptive optics and its resolution is worse than atmospheric turbulence, this parameter should be set to the seeing value (see Figure 1).

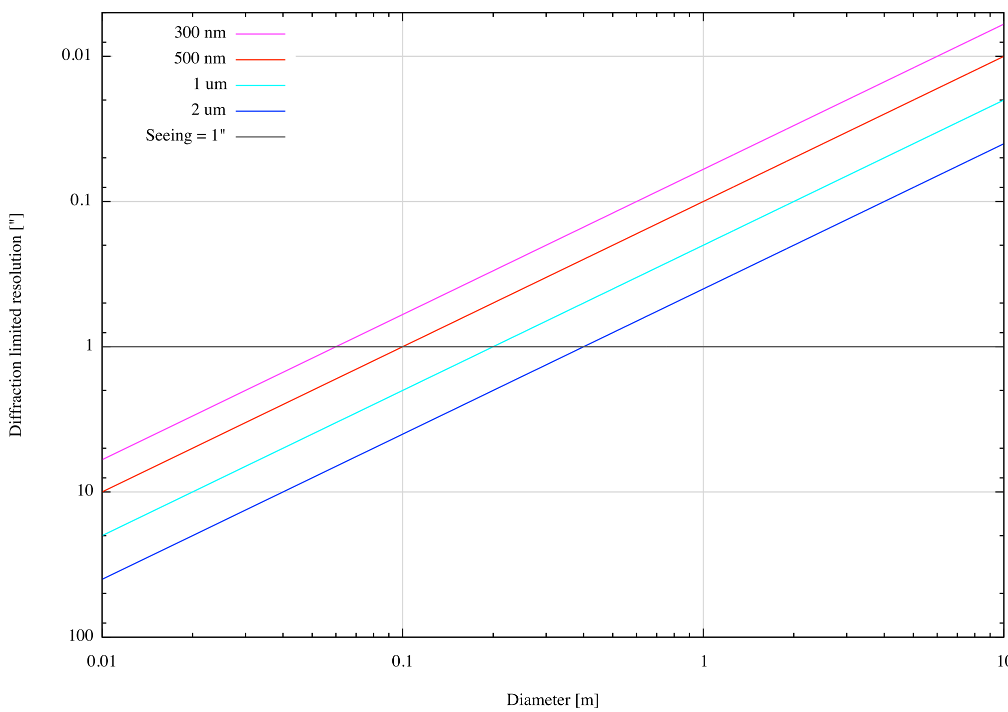


Figure 1: Diffraction limited resolution of telescopes with different diameter in four different wavelengths: 300, 500, 1000 and 2000 nm

- `spectroscopy` : 'yes' providing a cube data in wavelength range of $\lambda_{min}[A] - -\lambda_{max}[A]$ with the spectral resolution of R. 'no' does not provide any spectroscopic data.
- `lminspec` : minimum value of the wavelength for spectroscopy ($\lambda_{min}[A]$).
- `lmaxspec` : maximum value of the wavelength for spectroscopy ($\lambda_{max}[A]$).
- `Rspec` : spectral resolution of the instrument ($R = \frac{\lambda}{\Delta\lambda}$).
- `OBtreatment` : 'yes' uses TLUSTY SEDs for O and B type stars
- `Adaptiveoptics` : 'yes' the flux of the star will distribute partially in the airy pattern and the halo.
- `SR` : Strehl ratio, value between 0.0-1.0. If SR=1.0 the images are as perfect as space telescope's images.
- `seeing` : atmospheric resolution (FWHM of the halo) [arcsecond]
- `velocitydis` : 'yes' will apply Doppler shift in the spectroscopic data, 'no' does not apply any Doppler shift in the spectra.
- `alphai`, `bettai`, `gammai` : Euler angles for rotation [degree], rotation around x, y and z, respectively.
  If all of them are zero, then output image is X-Y plane.

  [0, 0, 0] –> X-Y

  [90, 0, 0] –> X-Z

  [0, 90, 0] –> Y-Z
- SNR: Signal to Noise ratio for the faintest star (e.g. 2.0, the noise will be as high as twice of the maximum flux value of the faintest star in the FOV, $noise = \frac{F/(2\pi\sigma^2)}{SNR}$, F =flux of the faintest star, $\sigma^2 = \frac{FWHM^2}{4\ Ln(2)}$).

3 Output

- `*_image.fits` : 2D fits image

- `*_star_info.txt` : contains the information of the stellar sources in the FoV This file contains 11 columns and each line shows the information of a given star.

  mass[$M_\odot$], Logage[yr], Metallicity, LogTeff[K], Logg, LogL/$L_\odot$, A_V, mag, X[pix], Y[pix], assignedSED

  If spectroscopy='yes' the two other outputs:

- `*_cube_spectra.fits` : 3D cube, X-Y is the position of stellar sources, Z is flux in different wavelengths

- `*_Lambda.txt` : the wavelengths [A] which is used for the 3rd dimension of the spectral-cube

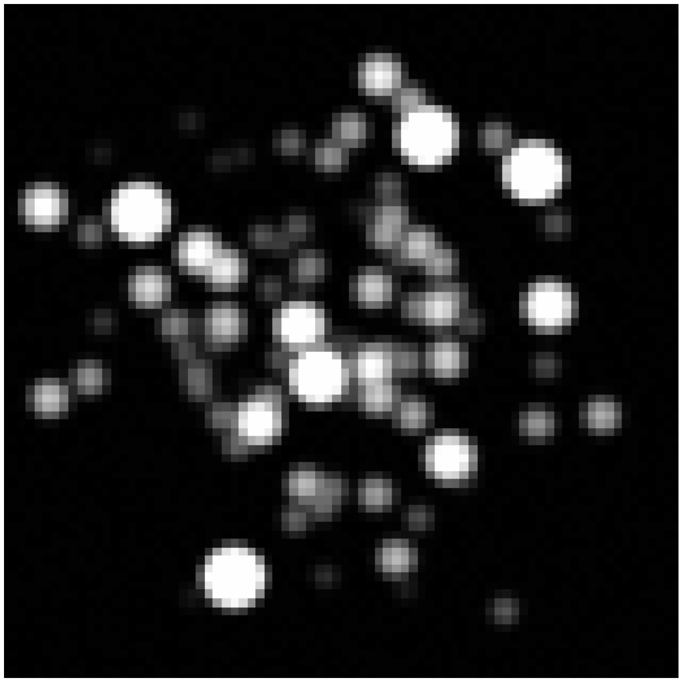
4 Example

In the folder "Examples" we created three files: Teststar1.txt , Teststar2.txt , Testcloud1e3.txt

- Teststar1.txt : This file can be used for filestar. There are 100 stars within a radius of 1pc with a total mass of about 104 $M_\odot$. These stars all have the same age (2Myr) and metallicity (Z=0.015 $Z_\odot$) without any extinction (cloud density values are zero).

- Teststar2.txt : This file can be used for filestar. Similar to Teststar1.txt, except that stars have three different ages of 1.0, 2.0 and 5 Myr and the cloud column density (last column) has random values between 20-80 [$M_\odot/pc^2$] for stellar sources.

- Testcloud1e3.txt : This is an example of the filecloud, generated by standard SPH code. This cloud contains 10^5 particles with mass of 0.01 $M_\odot$, so the total mass of the cloud is 10^3 $M_\odot$. This cloud has a Plummer density profile within a radius of 5.0pc.



```
pro MYOSOTIS

  project_name = 'test2'    ; Name of the project
  filestar = 'Examples/Teststar2.txt' ; Star's information file (should be 10 columns)
  filecloud= 'NoCloud'      ; Cloud's information file (should be 8 columns). Will be needed if Columndensities = 'sph'
  Columndensities= 'user'   ; 'sph': reads the cloud information file, 'user': reads it from the filestar, last column in the unit of [Msun/pc2]

  filter = 'Filters/generic/johnson/Generic-Johnson.V.dat' ;choose the path of your favourite filter!

  res  = 0.1           ; pixel resolution [arcsec/pix]
  fovx = 8             ; Field-of-view X  [arcsec]
  fovy = 8             ; Field-of-view  Y [arcsec]
  fwhm = 0.2           ; FWHM of the PSF, angular resolution of the instrument
  PSFtype= 'gaussian'   ;'airy' Type of PSF for distribution of the stellar fluxes on the detector: 'gassian' or 'airy'

  distance = 50000.      ; Distance of the observer from the reference in filestar and filecloud [pc]
  EXTmodel = 'Dmodel'    ; Extinction model, choose either 'Dmodel' OR 'Fmodel' (see the manual for more information on these models)
  Rv       = 3.1         ; Rv should be 3.1 or 4.0 or 5.5 if EXTmodel='Dmodel', otherwise can be set to any value.

  OBtreatment    = 'yes'  ; Uses TLUSTY SEDs for stars with Teff > 15000 K
  Adaptiveoptics = 'no'   ; Using of adaptive optics
  SR = 1.0                ; Strehl Ratio, should be between 0.0 - 1.0
  seeing = 0.8            ; Seeing [arcsec]

  spectroscopy = 'no'     ; Spectroscopy output, choose 'yes' or 'no'
  lminspec     = 3900.    ; Minimum wavelength [A] should be set within your filter transparency
  lmaxspec     = 5100.    ; Maximum wavelength [A]
  Rspec        = 700      ; Spectral resolution (please check your SED library, should not be larger than the resolution of the SEDs)

  velocitydis  = 'no'     ; 'yes' or 'no' : Adding Doppler shift on the spectra according to the velocity of the stars

  ;Euler angles for rotation [degree]:
  ;if all of them are zero, then outout image is X-Y
  ;[0,0,0] --> X-Y
  ;[90,0,0] --> X-Z
  ;[0,90,0] --> Y-Z
  alphai = 0   ; rotation around x [degree]
  bettai = 0   ; rotation around y [degree]
  gammai = 0   ; rotation around z [degree]

  SNR = 5.0    ; Signal to Noise ratio for the faintest star in the FOV
```

Figure 2: Top: Example of the image provided by MYPOSOTIS in logscale. The filestar is Teststar2.txt from the examples. The initial parameters chosen to create this image (screenshot from IDL code) is given in the bottom.

A List of Filters

Here is the list of provided Filters which User can select directly. User can add her/his own Filter [2].

```
Filters/2mass/2MASS-2MASS.H.dat
Filters/2mass/2MASS-2MASS.J.dat
Filters/2mass/2MASS-2MASS.Ks.dat
Filters/Gaia/GAIA0.G.dat
Filters/Gaia/GAIA0.Gbp.dat
Filters/Gaia/GAIA0.Grp.dat
Filters/GCPD/GCPD-JHKLMN.Lp.dat
Filters/GCPD/GCPD-JHKLMN.Lpp.dat
Filters/GCPD/GCPD-JHKLMN.N.dat
Filters/gemini/Gemini-Flamingos2.H.dat
Filters/gemini/Gemini-Flamingos2.HK.dat
Filters/gemini/Gemini-Flamingos2.J.dat
Filters/gemini/Gemini-Flamingos2.JH.dat
Filters/gemini/Gemini-Flamingos2.Jlow.dat
Filters/gemini/Gemini-Flamingos2.Ks.dat
Filters/gemini/Gemini-Flamingos2.Y.dat
Filters/gemini/Gemini-TReCS.l.dat
Filters/gemini/Gemini-TReCS.n.dat
Filters/generic/bessell/Generic-Bessell.B.dat
Filters/generic/bessell/Generic-Bessell.I.dat
Filters/generic/bessell/Generic-Bessell.R.dat
Filters/generic/bessell/Generic-Bessell.U.dat
Filters/generic/bessell/Generic-Bessell.V.dat
Filters/generic/bessell/Bessell_1988_J.dat
Filters/generic/bessell/Bessell_1988_K.dat
Filters/generic/johnson/Generic-Johnson.B.dat
Filters/generic/johnson/Generic-Johnson.I.dat
Filters/generic/johnson/Generic-Johnson.J.dat
Filters/generic/johnson/Generic-Johnson.M.dat
Filters/generic/johnson/Generic-Johnson.R.dat
Filters/generic/johnson/Generic-Johnson.U.dat
```

[2] see full list of filters in http://svo2.cab.inta-csic.es/theory/fps3/index.php?mode=browse

```
Filters/generic/johnson/Generic-Johnson.V.dat
Filters/generic/stromgren/Generic-Stromgren.b.dat
Filters/generic/stromgren/Generic-Stromgren.u.dat
Filters/generic/stromgren/Generic-Stromgren.v.dat
Filters/generic/stromgren/Generic-Stromgren.y.dat
Filters/geneva/Geneva-Geneva.B.dat
Filters/geneva/Geneva-Geneva.B1.dat
Filters/geneva/Geneva-Geneva.B2.dat
Filters/geneva/Geneva-Geneva.G.dat
Filters/geneva/Geneva-Geneva.U.dat
Filters/geneva/Geneva-Geneva.V.dat
Filters/geneva/Geneva-Geneva.V2.dat
Filters/gtc/osiris/GTC-OSIRIS.F643.dat
Filters/gtc/osiris/GTC-OSIRIS.F648.dat
Filters/gtc/osiris/GTC-OSIRIS.F657.dat
Filters/gtc/osiris/GTC-OSIRIS.F666.dat
Filters/gtc/osiris/GTC-OSIRIS.F680.dat
Filters/gtc/osiris/GTC-OSIRIS.F694.dat
Filters/gtc/osiris/GTC-OSIRIS.F709.dat
Filters/gtc/osiris/GTC-OSIRIS.F723.dat
Filters/gtc/osiris/GTC-OSIRIS.F738.dat
Filters/gtc/osiris/GTC-OSIRIS.F754.dat
Filters/gtc/osiris/GTC-OSIRIS.F770.dat
Filters/gtc/osiris/GTC-OSIRIS.F785.dat
Filters/gtc/osiris/GTC-OSIRIS.F802.dat
Filters/gtc/osiris/GTC-OSIRIS.F819.dat
Filters/gtc/osiris/GTC-OSIRIS.F838.dat
Filters/gtc/osiris/GTC-OSIRIS.F858.dat
Filters/gtc/osiris/GTC-OSIRIS.F878.dat
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Filters/gtc/osiris/GTC-OSIRIS.F902.dat
Filters/gtc/osiris/GTC-OSIRIS.F911.dat
Filters/gtc/osiris/GTC-OSIRIS.F919.dat
Filters/gtc/osiris/GTC-OSIRIS.F924.dat
Filters/gtc/osiris/GTC-OSIRIS.F927.dat
Filters/gtc/osiris/GTC-OSIRIS.F932.dat
Filters/gtc/osiris/GTC-OSIRIS.F936.dat
Filters/gtc/osiris/GTC-OSIRIS.F940.dat
```

```
Filters/gtc/osiris/GTC-OSIRIS.sdss_g.dat
Filters/gtc/osiris/GTC-OSIRIS.sdss_i.dat
Filters/gtc/osiris/GTC-OSIRIS.sdss_r.dat
Filters/gtc/osiris/GTC-OSIRIS.sdss_z.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F220W.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F250W.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F330W.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F344N.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F435W.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F475W.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F502N.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F550M.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F555W.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F606W.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F652W.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F658N.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F660N.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F775W.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F814N.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F850LP.dat
Filters/hst/acs_hrc/HST-ACS_HRC.F892N.dat
Filters/hst/acs_sbc/HST-ACS_SBC.F115LP.dat
Filters/hst/acs_sbc/HST-ACS_SBC.F122M.dat
Filters/hst/acs_sbc/HST-ACS_SBC.F125LP.dat
Filters/hst/acs_sbc/HST-ACS_SBC.F140LP.dat
Filters/hst/acs_sbc/HST-ACS_SBC.F150LP.dat
Filters/hst/acs_sbc/HST-ACS_SBC.F165LP.dat
Filters/hst/acs_sbc/HST-ACS_SBC.PR110L.dat
Filters/hst/acs_sbc/HST-ACS_SBC.PR130L.dat
Filters/hst/acs_wfc/HST-ACS_WFC.F435W_77.dat
Filters/hst/acs_wfc/HST-ACS_WFC.F435W_81.dat
Filters/hst/acs_wfc/HST-ACS_WFC.F475W_77.dat
Filters/hst/acs_wfc/HST-ACS_WFC.F475W_81.dat
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```

```
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```

```
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Filters/jwst/MIRI/JWST_MIRI.F1000W.dat
Filters/jwst/MIRI/JWST_MIRI.F1130W.dat
Filters/jwst/MIRI/JWST_MIRI.F1280W.dat
Filters/jwst/MIRI/JWST_MIRI.F1500W.dat
Filters/jwst/MIRI/JWST_MIRI.F1800W.dat
Filters/jwst/MIRI/JWST_MIRI.F2100W.dat
Filters/jwst/MIRI/JWST_MIRI.F2550W.dat
Filters/jwst/NIRCam/JWST_NIRCam.F070W.dat
Filters/jwst/NIRCam/JWST_NIRCam.F090W.dat
Filters/jwst/NIRCam/JWST_NIRCam.F115W.dat
Filters/jwst/NIRCam/JWST_NIRCam.F140M.dat
Filters/jwst/NIRCam/JWST_NIRCam.F150W.dat
Filters/jwst/NIRCam/JWST_NIRCam.F150W2.dat
Filters/jwst/NIRCam/JWST_NIRCam.F162M.dat
Filters/jwst/NIRCam/JWST_NIRCam.F164N.dat
Filters/jwst/NIRCam/JWST_NIRCam.F182M.dat
Filters/jwst/NIRCam/JWST_NIRCam.F187N.dat
```

```
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