PhoSim-NIRCam: How to install

- Click the download button at the front page of the PhoSim-NIRCam website at,

  https://fenrir.as.arizona.edu/phosim

- Unpack the downloaded file:

  $ tar xvzf PhoSim-NIRCam.tar.gz

- To compile PhoSim-NIRcam,

```
$ cd PhoSim-NIRCam
$ cd phosim-nircam
$ ./configure
   (then type "a" to install cfitsio and fftw3)
$ make
```

That's it!

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PhoSim-NIRCam: How to run

- To test if PhoSim-NIRCam works properly on your machine, run the shell script **mkimage** in the top directory (**PhoSim-NIRCam**):

```
$ ./mkimage &
```

  This will produce a simulated LW F356W image (Tint = 600 sec; containing ~1200 sources) with geometric distortion and diffraction-limited PSF (but without any detector or background noise) in the directory **output.lw_geo_diff**, together with the log file **log.lw_geo_diff**. The runtime will typically be ~20 min for this example.

- The shell script **mkimage** contains other examples of how to run **phosim** with the simple wrapper **run_phosim**. Uncomment any of the lines to test other modes, such as producing SW F200W images or point-source (22 AB mag) images for deriving magnitude zero-points.

- In essence, running PhoSim-NIRCam only requires issuing a one-line command as follows:

```
$ phosim <CatalogFile> –c <CommandsFile> –i <Channel>
```

  - **CatalogFile** (called instanceCatalog file by LSST/PhoSim) specifies the configuration of the observation (e.g., pointing coordinates, integration time) and astrophysical inputs (e.g., source coordinates, brightness, SED, morphology).
  - **CommandsFile** (called physicsCommands file by LSST/PhoSim) modifies the default physics in PhoSim.
  - **Channel** (called instrumentSiteDirectory by LSST/PhoSim) points to the directory that contains the relevant telescope/instrument (as well as site) characteristic files. In the case of PhoSim-NIRCam, this is either **nircam_sw** or **nircam_lw**.

- Here is an example command line that can be run inside the **phosim-nircam** directory:

```
$ ./phosim nircam/phosim_lw.cat \\
       –c nircam/geo_diff –i nircam_lw
```

  Note that in this particular case, the CatalogFile (phosim_lw.cat) and CommandsFile (geo_diff) are located in the directory **nircam** (in **phosim-nircam**). This is essentially what **mkimage** does when used as distributed.

- PhoSim-NIRCam can also generate a sky background, but this feature is still under testing. At the moment, an appropriate sky background needs to be added to the simulated image manually (see the Quick-Guide **Background** for more detail).

PhoSim-NIRCam: CatalogFile

- CatalogFile specifies various observing parameters (e.g., filter, pointing coordinates, integration time), and includes a catalog of sources that will be used for image simulation.

- See "phosim_sw.cat" and "phosim_lw.cat" in the **phosim-nircam/nircam** directory for example CatalogFiles. The only difference between these two files is the filter specification (see below).

- The CatalogFile "phosim_sw.cat" looks like the following:

```
Opsim_filter 31
Unrefracted_RA_deg 53.117046
Unrefracted_Dec_deg -27.804967
Opsim_obshistid 0001
SIM_NSNAP 1
SIM_VISTIME 600.0
 object 0.0 53.092995 -27.954538 26.24 ../sky/nir_sed_flat.txt 0 0 0 0 0 0 sersic2d  1.42 0.46 -14.61 8.00
 object 0.0 53.102890 -27.959661 26.39 ../sky/nir_sed_flat.txt 0 0 0 0 0 0 sersic2d  0.22 0.03 -75.26 0.80
 object 0.0 53.10168  -27.958479 26.29 ../sky/nir_sed_flat.txt 0 0 0 0 0 0 sersic2d  0.46 0.11 -33.00 0.75
 object 0.0 53.102280 -27.958651 25.57 ../sky/nir_sed_flat.txt 0 0 0 0 0 0 sersic2d 23.58 9.19 -56.35 8.00
 object 0.0 53.090561 -27.958500 28.05 ../sky/nir_sed_flat.txt 0 0 0 0 0 0 sersic2d  0.16 0.09 -89.22 0.59
 .....
 .....
```

- The CatalogFile starts with the following lines:
  - Filter selection
    - `Opsim_filter 31 (F200W for SW)`
    - `Opsim_filter 19 (F356W for LW)`
    - See the table on the next page for the filter specification numbers (which is Table 6 in "Implementation of the James Webb Space Telescope Near-Infrared Camera (NIRCam) in PhoSim" by Colin Burke).
  - Pointing coordinates:
    - `Unrefracted_RA_deg 53.117046`
    - `Unrefracted_DEC_deg -27.804967`
  - Image ID number:
    - `Opsim_obshistid 0001`
    - This can be any integer ID number (with or without preceding 0's) that will be added to the image file name.
  - Number of exposures & total integration time (in seconds)
    - `SIM_NSAMP 1`
    - `SIM_VISTIME 600.0`
    - If `SIM_NSAP` is set to 6, PhoSim-NIRCam will create 6 images with an integration time of 100 sec each.

Number	NIRCam Filter
0	No filter
1	F070W_A
2	F070W_ABmean
3	F070W_B
4	F090W_A
5	F090W_ABmean
6	F090W_B
7	F115W_A
8	F115W_ABmean
9	F115W_B
10	F140M_A
11	F140M_ABmean
12	F140M_B
13	F150W_A
14	F150W_ABmean
15	F150W_B
16	F150W2_A
17	F150W2_ABmean
18	F150W2_B
19	F162M_A
20	F162M_ABmean
21	F162M_B
22	F164N_A
23	F164N_ABmean
24	F164N_B
25	F182M_A
26	F182N_ABmean
27	F182N_B
28	F187N_A
29	F187N_ABmean
30	F187N_B
31	F200W_A
32	F200W_ABmean
33	F200W_B
34	F210M_A
35	F210M_ABmean
36	F210M_B
37	F212N_A
38	F212N_ABmean
39	F212N_B

Number	NIRCam Filter
0	No filter
1	F250M_A
2	F250M_ABmean
3	F250M_B
4	F277W_A
5	F277W_ABmean
6	F277W_B
7	F300M_A
8	F300M_ABmean
9	F300M_B
10	F322W2_A
11	F322W2_ABmean
12	F322W2_B
13	F323N_A
14	F323N_ABmean
15	F323N_B
16	F335M_A
17	F335M_ABmean
18	F335M_B
19	F356W_A
20	F356W_ABmean
21	F356W_B
22	F360M_A
23	F360M_ABmean
24	F360M_B
25	F405M_A
26	F405M_ABmean
27	F405M_B
28	F410M_A
29	F410M_ABmean
30	F410M_B
31	F430M_A
32	F430M_ABmean
33	F430M_B
34	F444W_A
35	F444W_ABmean
36	F444W_B
37	F460M_A
38	F460M_ABmean
39	F460M_B
40	F466N_A
41	F466N_ABmean
42	F466N_B
43	F470N_A
44	F470N_ABmean
45	F470N_B
46	F480M_A
47	F480M_ABmean
48	F480M_B

- The remaining lines specify the properties of each source line by line with the following parameters:

  `object ID RA DEC MAG_NORM SED_NAME REDSHIFT GAMMA1 GAMMA2 KAPPA DELTA_RA DELTA_DEC SOURCE_TYPE source_pars` ~~`DUST_REST_NAME dust_pars_1 DUST_LAB_NAME dust_pars_2`~~ (dust parameters are not used in the examples)

  - PhoSim calculates filter magnitudes using the source SED (`SED_NAME`), normalization magnitude (`MAG_NORM` at 500 nm/(1+z), which is equivalent to observed V_{AB} or g_{AB}), and redshift (`REDSHIFT`). For the examples here, we used a flat f_ν SED (sed_flat_fnu.txt) and z=0 with the observed HST/WFC3 H_{160} magnitudes (in AB).
  - SED files (e.g., sed_flat_fnu.txt) should be saved in /data/SEDs.
  - `SOURCE_Type` specifies the name of the spatial model (i.e. morphology). Here, we used the 4-parameter sersic2D profile (SOURCE_TYPE, source_pars).
  - GAMMA1, GAMMA2, and KAPPA are parameters associated with weak-lensing effects, and are set to 0 here.
  - DELTA_RA, DELTA_DEC are also set to 0.
  - See the next page for a more detailed description of the catalog parameters (taken from https://confluence.lsstcorp.org/display/PHOSIM/Instance+Catalog).

Astrophysical Data	
ID	A floating point number to keep track of the object, which is unused by phosim except for diagnostic source information
RA	The right ascension of the center of the object or image in decimal degrees.
DEC	The declination of the center of the object in decimal degrees
MAG_NORM	The normalization of the flux of the object in AB magnitudes at (500 nm)/(1+z) (which is roughly equivalent to V (AB) or g (AB)).
SED_NAME	The name of the SED file with a file path that is relative to the data directory
REDSHIFT	The redshift (or blueshift) of the object. Note that the SED does not need to be redshifted if using this
GAMMA1	The value of the shear parameter gamma1 used in weak lensing.
GAMMA2	The value of the shear parameter gamma2 used in weak lensing.
KAPPA	The value of the magnification parameter in weak lensing.
DELTA_RA	The value of the declination offset in radians. This can be used either for weak lensing or objects that moved from another exposure if you do not want to change the source position in the first two columns.
DELTA_DEC	The value of the declination offset in radians. This can be used either for weak lensing or objects that moved from another exposure if you do not want to change the source position in the first two columns.
SOURCE_TYPE	The name of the spatial model to be used as defined below.
spatial_pars	The associated parameters for each spatial model.There could be none or many. While the parser is reading the model it looks for more parameters based on the name of the model.
DUST_REST_NAME	Dust model name in the object's rest frame. This is either the ccm for the CCM model, or calzetti for the calzetti model. If no dust model is desired, then put none for this field.
dust_pars_1	The parameters for both the calzetti and CCM are the A_v followed by the R_v value. If no dust model is used, do not use parameters
DUST_LAB_NAME	Dust model name in the lab frame. This is either the ccm for the CCM model, or calzetti for the calzetti model. If no dust model is desired, then put none *for this field.*
dust_pars_2	The parameters for both the calzetti and CCM are the A_v followed by the R_v value. If no dust model is used, do not use parameters

Spatial Models		
point	No parameters	This is a model primarily used for stars, but also unresolved objects.
gauss	1 parameter: sigma in arcseconds	This is a model for a gaussian-shaped object.
movingpoint	2 parameters: the derivative of the velocity arcseconds per second along the ra direction, the derivative of the velocity in arcseconds per second along the dec direction	Moving object (e.g. asteroid)
sersic2D	4 parameters: (half-light radius of semi-major axis in arcseconds, half-light radius of semi-minor axis in arcseconds, position angle in degrees, sersic index	2-D elliptical Sersic model
sersic	6 parameters: size of axis 1 in arcseconds, size of axis 2 in arcseconds, size of axis 3 in arcseconds, sersic index, polar angle in radians, position angle in degrees	3-D ellipsoidal Sersic model
If the SOURCE_TYPE contains the word fits or fit,it will look for that file in the image directory	2 parameters: pixel size (in arcseconds) and rotation angle (in degrees). RA goes to the left and DEC goes up in physical coordinates Note that PhoSim will not use the header information, because you may want to use the same image in multiple field locations	Complex morphology spatial truth images

PhoSim-NIRCam: CommandsFile

- The default physics in PhoSim can be modified by issuing a series of physics override commands in CommandsFile.

- We provide the following three CommandsFiles for the use with JWST/NIRCam (these can be found in the **nircam** directory):
    - **geo** – geometric distortion only
    - **diff** – diffraction-limited PSF only
    - **geo_diff** – geometric distortion and diffraction-limited PSF.
    - Only **geo_diff** will produce photometrically accurate images.   The CommandsFiles **geo** and **diff** are used for diagnostic purposes only.
    - It is not necessary for the general user to understand what **phosim** commands do, but the contents of these CommandsFiles are listed below for information.
- geo
    - cleareverythingbutbody
    - contaminationmode 1
    - zenith_v 1000.0 (set the background level to zero)
    - raydensity 0.0 (turn off cosmic rays)
    - telescopemode 1
    - detectormode 0
    - diffractionmode 0
    - tiltx -0.02430555556
    - tilty -0.135916667

- diff
    - cleareverything
    - contaminationmode 1
    - zenith_v 1000.0
    - raydensity 0.0
    - telescopemode 0
    - detectormode 1
    - ccdtemp37
    - diffractionmode 1
    - pupilscreen 1

- geo_diff
    - cleareverythingbutbody

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- contaminationmode 1
- zenith_v 1000.0
- raydensity 0.0
- telescopemode 1
- detectormode 1
- ccdtemp 37
- diffractionmode 1
- pupilscreen 1
- tiltx -0.02430555556
- tilty -0.135916667

PhoSim-NIRCam: Photometry

- To determine the magnitude zero-point for a given simulated image, create a point-source image using the same filter and compare the input magnitude and measured source count, which is the number of electrons.
- For this purpose, we provide two catalogs, **star_sw.cat** and **star_lw.cat** (see **mkimage** for how to create images using these catalogs). Don't forget to set the filter number properly in the catalogs. These catalogs will produce a point-source image with a brightness of 22 AB mag. Since the source is defined with a flat-fν SED, its brightness, when expressed in the AB magnitude, is always 22 mag regardless of the filter selected.
- The catalogs **star_sw.cat** and **star_lw.cat**, when used as they are, will create F200W and F356W point-source images with an integration time of 600 sec. The measured source-flux counts are 167,268 e- for F200W (with an r= 3.37" aperture) and 153,418 e- for F356W (with an r=6" aperture), so the corresponding magnitude zero-points (i.e., AB mag for e-/s) are,

  Mzero(F200W) = 22 + 2.5 log (167268/600) = 28.11

  Mzero(F356W) = 22 + 2.5 log (153418/600) = 28.02

  The zero-points for other filters can be calculated in a similar manner.
- Our preliminary analysis shows that the magnitude zero-points measured with PhoSim-NIRCam images are generally within 10-20% of the expected values. However, please note that an extensive photometric analysis is yet to be carried out.

PhoSim-NIRCam: Background

- PhoSim-NIRCam does have the capability to generate a sky background automatically, but this feature is still under testing. At the moment, an appropriate sky background needs to be added to the simulated image manually.
- First, estimate the sky background for the target field. For example, you can use the JWST Backgrounds Tool (https://jwst-docs.stsci.edu/display/JPP/JWST+Backgrounds+Tool).
- The pixel scale of the SW image is 0.031". If the expected background is 0.1 MJy/sr, the corresponding sky count in electron will be,

$$0.1e6 \times (\pi/180/3600 \times 0.031)^2 / (3631 \times 10^{(-0.4 \times 28.11)}) = 0.11 \text{ (e-/s)}$$

- The pixel scale of the LW image is 0.063". For the same background of 0.1 MJy/sr, the corresponding sky count in electron will be,

$$0.1e6 \times (\pi/180/3600 \times 0.063)^2 / (3631 \times 10^{(-0.4 \times 28.02)}) = 0.41\text{(e-/s)}$$

- The simulated images produced by **mkimage** has an integration time of 600 sec. Therefore, a sky background of 66 and 246 e- were added to the F200W and F356W images, respectively, with the corresponding Poisson noise.
- We anticipate that PhoSim-NIRCam will be interfaced with the JWST Backgrounds Tool soon so that an appropriate sky background will be included in simulated images automatically, but until then, please add a sky background manually in a similar manner.

PhoSim-NIRCam: Known Issues & Development Plan

- **Known Issues:**
    - **Saturation**: The detector saturation level is currently set to 100,000 e-. The current version of PhoSim-NIRCam will make saturated pixels bleed like CCD detectors, which is not the case for the NIRCam IR arrays.
    - **WCS:** The WCS parameters recorded in the FITS header correspond to those of the distortion-free image. This means that when the input source coordinates are plotted using the WCS in the image header, the plotted positions would not coincide with those of sources seen in the image, especially toward the edges of the FOV, where the effect of geometric distortion is significant (see the "JWST/NIRCam LW Field Distortion" image on the website).
    - **No detector/background noise**: PhoSim-NIRCam currently produces images with no detector/background noise (i.e., with source photon noise only). The Quick Guide **Background** describes how to calculate and insert an appropriate background signal in the simulated images.
- **On-going development**
    - Upgrade to PhoSim 4.0 (multi-threading, GUI, etc.)
    - Generate backgrounds inside PhoSim-NIRCam by using the existing PhoSim commands.
    - Add a capability to simulate NIRCam readout modes.
    - Include realistic detector noise by interfacing with pyNRC developed by J. Leisenring.
- **Features under consideration**
    - Interface with the JWST Backgrounds Tool for automatic sky background calculation.
    - Make the output file/header format consistent with that of the real NIRCam data so that the simulated data can be run through the NIRCam data processing pipeline.
    - Provide an option to produce WCS header parameters that incorporate geometric distortion.

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