A PhoSim Primer

Version 0.1

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An Introduction to PhoSim

What is PhoSim?

PhoSim stands for Photon Simulator. It is a set of files used to model the optics, electronics, and operating conditions of the Large Synoptic Survey Telescope (LSST) and generate simulated images. PhoSim is an interactive command-line program; users specify the operating conditions of the telescope and observatory environment, and light sources measured by the camera, via an input text file. Options such as dome settings, exposure time, number of consecutive “snaps,” and more make PhoSim useful for testing and planning purposes. It can even be adjusted to simulate telescopes other than LSST with some straightforward changes.

What does PhoSim do?

The purpose of PhoSim is to generate realistic images that simulate those that will be generated by LSST. The basics of this process are as follows: PhoSim reads a text file with operating conditions and light source information, and it translates each light source to a pixel location on a chip. Then, taking into account environmental and electronic factors, it models photons streaming from each light source to the CCD detector. This generates a set of FITS files containing information about location and number of detected photons.

What does PhoSim include in its model?

PhoSim is a detailed simulator. It models optical, electronic, environmental, and other physical processes. Here are some of the factors included in the model:

Environmental: cloud absorption, wind, turbulence intensity

Optical: reflection, refraction, and diffraction of mirrors, lenses, and coatings; optical design, focal plane layout

Electronic: photoelectric conversion, saturation, blooming, charge diffusion, read noise, dark current, gain, overscans, hot pixels, hot columns, dead pixels

Physical: dust absorption, atmospheric dispersion, atmospheric scattering, telescope tracking, alignment errors, dome seeing, cosmic ray properties

(A full list of processes modelled is available at: https://www.lsst.org/scientists/simulations/phosim)

What is PhoSim used for?

PhoSim is used by the LSST science collaboration for testing and planning. Simulated images help to determine what observational complications to plan for and what kinds of data will be useable or not useable.

How to Use PhoSim

Online Resources

Almost any question you have about PhoSim has been answered online. Here are some of the online resources that give information about operating and understanding PhoSim:

1. LSST Website
   https://www.lsst.org/scientists/simulations/phosim
   Contains basic information about the PhoSim and related simulators.
2. PhoSim wiki at BitBucket
   https://bitbucket.org/phosim/phosim_release/wiki/Home
   Contains basic and detailed information about obtaining, running, and modifying PhoSim.
3. Official PhoSim informational document
   https://lsst.rcac.purdue.edu/doc/phosim_reference.pdf
   A PDF which contains detailed information about the design and operations of PhoSim.

Obtaining PhoSim

The PhoSim code can be downloaded from the PhoSim github repository, and the walkthrough for how to set up and test PhoSim can be found here:
https://bitbucket.org/phosim/phosim_release/wiki/Using%20PhoSim

The Basics of Using PhoSim

Before attempting to run PhoSim, some information will be helpful:

Firstly, PhoSim runs in the command line and requires an input file to run. This input is called the instance catalog, which is a text file consisting of two important pieces: operation settings and the positions of light sources.

Secondly, PhoSim models many details of observation. For nearly all of these settings, PhoSim has a default configuration, which models the LSST telescope and an assumed LSST observational setup. Possible goals of changing the defaults could be to represent a different telescope, or to represent a different observational strategy, or to speed up the simulation by simplifying it.

Thirdly, there are some command line shortcuts that allow you to change default settings without editing your instance catalog.

The Instance Catalog
The instance catalog required to run PhoSim will be written by you to serve your modelling goals. This is a text file which describes operating settings and the light sources that emit photons.

Settings
The instance catalog begins with a list of settings. Each of these settings is represented by a new line in the instance catalog with a keyword and an associated numerical value.

Physical processes: PhoSim models many physical processes, each of which can be turned on and off. The default setting is that each process is turned on, making the simulation as accurate as possible. In the instance catalog, putting a 0 after the keyword turns the process model off, and putting a 1 turns the process model on.

Observation configuring: Other settings include exposure time, number of consecutive images, time between consecutive images, filter, etc. Each of these settings must be set to a value. If these are not set to a value, they are set to a default. A full list of settings, keywords, and default values is available at: https://confluence.lsstcorp.org/display/PHOSIM/Instance+Catalog.

Light sources
The second piece of the instance catalog is a list of light sources. These source lists, or catalogs, can be either written or downloaded.
If you want to create your own catalog, or understand the information contained in a catalog you have downloaded, the following information is necessary:
Each object is represented by one line at the end of the instance catalog file, beginning with the word "object." For each object, the following items must be designated, in order, with a whitespace between each value:

- ID number (not used by PhoSim, but used by you to distinguish between objects)
- Right ascension
- Declination
- (Magnitude) Normalization of the flux in AB magnitudes at 500 nm/(1+z)
- **Spectral Energy Distribution (SED) file (full path)**
- Redshift
- Gamma 1 (weak lensing)
- Gamma 2 (weak lensing)
- Magnification parameter (weak lensing)
- RA offset (radians)
- Dec offset (radians)

- Source type (spatial model used by PhoSim: point, gauss, movingpoint, sersic, sersic2d, or more complicated model (FITS file) and associated parameters
- Dust rest frame model name and associated parameters (can be set to none)
- Dust lab frame model name name and associated parameters (can be set to none)

So, a simple object could read as follows:

`object 1 100 10 20 sedfile.txt 0 0 0 0 0 0 point none none`

Here the object ID number is 1, the right ascension is 100 and declination is 10 degrees North, the magnitude is 20, the SED file is "sedfile.txt," and so on. In the simplest model, dust models are both set to "none." PhoSim will use this information to simulate photons for each object.

The simplest catalog you could make would include the values for any operating conditions that do not have a default, and one astrophysical object. The object would require an associated SED file; a text file that describes a flat SED can be found in the PhoSim files under: `\data\sky\sed_flat.txt`

Following the formula above, one can easily create simple or complex catalogs full of a massive variety of objects.

For reference, here is a snapshot of a sample instance catalog:

mini_catalog

```
Unrefracted_RA 112
Unrefracted_Dec -35
Opsim_rotskypos 112
Opsim_rottelpos 0.559023062
Opsim_filter 1
Opsim_altitude 22.3365589
Opsim_azimuth 118.659768
Opsim_moonphase 0
Opsim_expmjd 58484
object 31045209446404 112.127152 -35.1095775 25.9733482 starSED/mlt/m2.3Full.dat.gz 0 0 0 0 0 0 point CCM 0.97022901 3.28717208 none
object 31849541430276 112.124094 -35.112892 25.9551262 starSED/mlt/m4.0Full.dat.gz 0 0 0 0 0 0 point CCM 0.97473641 3.29123981 none
object 31042887425028 112.126817 -35.1118198 27.6748117 starSED/mlt/m4.1Full.dat.gz 0 0 0 0 0 0 point CCM 0.97135586 3.28275049 none
object 32162734262276 112.128266 -35.1123254 22.6155855 starSED/kurucz/km50_6500.fits_g40_6580.gz 0 0 0 0 0 0 point CCM 0.97360956 3.28797006 none
object 31042891484164 112.119928 -35.1186206 28.5439105 starSED/mlt/m6.2Full.dat.gz 0 0 0 0 0 0 point CCM 0.97811696 3.28248074 none
object 31566730173444 112.119487 -35.1185658 26.6469104 starSED/mlt/m6.2Full.dat.gz 0 0 0 0 0 0 point CCM 0.92290069 3.09748087 none
object 31849543072772 112.123334 -35.1183126 17.9740613 starSED/kurucz/km10_5750.fits_g20_5910.gz 0 0 0 0 0 0 point CCM 0.97811696 3.28253904 none
object 31849542270980 112.123702 -35.115723 26.5565209 starSED/mlt/m2.9Full.dat.gz 0 0 0 0 0 0 point CCM 0.97699011 3.28835487 none
object 31042898974724 112.133375 -35.1200781 26.3345151 starSED/mlt/m4.2Full.dat.gz 0 0 0 0 0 0 point CCM 0.97473641 3.27232186 none
object 31849544301572 112.132255 -35.1181975 26.1450654 starSED/mlt/m2.1Full.dat.gz 0 0 0 0 0 0 point CCM 0.97360956 3.27722997 none
object 31849543708676 112.127642 -35.1182749 18.5820581 starSED/kurucz/km25_5750.fits_g15_5830.gz 0 0 0 0 0 0 point CCM 0.97586326 3.28660009 none
object 31042894464004 112.126966 -35.1183734 20.4050844 starSED/kurucz/km10_4750.fits_g00_4870.gz 0 0 0 0 0 0 point CCM 0.97586326 3.28643268 none
object 31566731260932 112.131329 -35.116017 24.4428428 starSED/mlt/m5.0Full.dat.gz 0 0 0 0 0 0 point CCM 0.88346063 2.97028356 none
object 31045210012676 112.1242 -35.1152698 28.5824533 starSED/mlt/m6.6Full.dat.gz 0 0 0 0 0 0 point CCM 0.96346791 3.24429804 none
object 31042889419780 112.124157 -35.114861 17.6986871 starSED/kurucz/km15_5500.fits_g10_5600.gz 0 0 0 0 0 0 point CCM 0.97360956 3.279906 none
object 31849542528004 112.127453 -35.1149435 20.4029818 starSED/mlt/m1.1Full.dat.gz 0 0 0 0 0 0 point CCM 0.78880399 2.65624156 none
object 31042894524420 112.127964 -35.1180299 18.4420846 starSED/kurucz/km10_4750.fits_g00_4870.gz 0 0 0 0 0 0 point CCM 0.9544528 3.21542011 none
object 32056255396868 112.117077 -35.1322807 26.3581264 starSED/mlt/m4.0Full.dat.gz 0 0 0 0 0 0 point CCM 0.98825892 3.26912872 none
object 32056255513604 112.119351 -35.1318365 25.8449133 starSED/mlt/m4.5Full.dat.gz 0 0 0 0 0 0 point CCM 0.98487837 3.25923655 none
object 31045210231812 112.116027 -35.1205407 25.1747996 starSED/mlt/m4.9Full.dat.gz 0 0 0 0 0 0 point CCM 0.96234106 3.236387 none
object 31849543332868 112.11396 -35.1229764 17.1129759 starSED/kurucz/km20_6000.fits_g25_6240.gz 0 0 0 0 0 0 point CCM 0.98375121 3.29808663 none
object 32162735580164 112.117153 -35.1243503 26.8619892 starSED/kurucz/km10_5000.fits_g15_5060.gz 0 0 0 0 0 0 point CCM 0.98825892 3.30535486 none
object 32162735499268 112.116816 -35.1241564 22.0537753 starSED/kurucz/km15_5750.fits_g25_5870.gz 0 0 0 0 0 0 point CCM 0.98375121 3.29133427 none
object 32056253365252 112.116346 -35.1238715 25.6783465 starSED/mlt/m3.9Full.dat.gz 0 0 0 0 0 0 point CCM 0.98262436 3.28897915 none
object 31849543464964 112.115726 -35.1225789 27.1605156 starSED/mlt/m4.2Full.dat.gz 0 0 0 0 0 0 point CCM 0.98375121 3.29916727 none
object 31042899346436 112.116626 -35.1274509 23.639065 starSED/mlt/m2.1Full.dat.gz 0 0 0 0 0 0 point CCM 0.98487837 3.27992224 none
object 32257739009028 112.114012 -35.1264774 28.2685984 starSED/mlt/m0.3Full.dat.gz 0 0 0 0 0 0 point CCM 0.98600522 3.28932219 none
object 32162735992836 112.115802 -35.127033 25.2545521 starSED/kurucz/km10_5250.fits_g15_5350.gz 0 0 0 0 0 0 point CCM 0.98825892 3.29353031 none
object 31042915185668 112.135634 -35.1343663 26.1516356 starSED/mlt/m6.0Full.dat.gz 0 0 0 0 0 0 point CCM 0.91839329 3.02611375 none
object 31849550613508 112.138646 -35.1349828 27.2824903 starSED/mlt/m2.4Full.dat.gz 0 0 0 0 0 0 point CCM 0.98149751 3.23089583 none
object 31042906251268 112.13073 -35.1279383 22.641648 starSED/kurucz/km40_4250.fits_g00_4250.gz 0 0 0 0 0 0 point CCM 0.98037066 3.25801176 none
object 31849548090372 112.135872 -35.1282728 25.3748941 starSED/mlt/m3.1Full.dat.gz 0 0 0 0 0 0 point CCM 0.97924381 3.25149827 none
object 31849548571652 112.134651 -35.1303916 19.3301816 starSED/kurucz/km20_5750.fits_g15_5790.gz 0 0 0 0 0 0 point CCM 0.98037066 3.2466737 none
object 31042909026308 112.124363 -35.1332087 24.5725986 starSED/mlt/m0.3Full.dat.gz 0 0 0 0 0 0 point CCM 0.98600522 3.25563507 none
object 31566736768004 112.128208 -35.1296531 25.9265317 starSED/mlt/m3.6Full.dat.gz 0 0 0 0 0 0 point CCM 0.98375121 3.26254076 none
object 31849547653124 112.127443 -35.1305076 26.7708942 starSED/mlt/m3.1Full.dat.gz 0 0 0 0 0 0 point CCM 0.98375121 3.25910383 none
object 32162738117636 112.128292 -35.1334865 26.6314315 starSED/mlt/m2.0Full.dat.gz 0 0 0 0 0 0 point CCM 0.98487837 3.24992683 none
object 31849548729348 112.133797 -35.1312138 28.472474 starSED/mlt/m5.5Full.dat.gz 0 0 0 0 0 0 point CCM 0.98149751 3.24709206 none
object 32162737380356 112.123874 -35.1314105 25.8659499 starSED/kurucz/km50_3750.fits_g20_3910.gz 0 0 0 0 0 0 point CCM 0.98600522 3.26365777 none
```

The SED Library

Each object in the catalog must have an associated spectral energy distribution, which is modelled by a 2-column text file with wavelengths and corresponding fluxes. There is an SED library accessible via the PhoSim documentation at: https://bitbucket.org/phosim/phosim_release/wiki/Using%20PhoSim under the heading "Usage." This library includes example SEDs for many astrophysical objects, such as galaxies, asteroids, and stars.

CatSim Catalogs

If your simulation purpose does not require specific object types, object magnitudes, or object locations, many realistic object catalogs can be found online. There is a program called CatSim designed to create realistic object catalogs and many of these are uploaded and findable via Google. For many CatSim catalogs, objects refer to the common SED library available through the PhoSim documentation. **CatSim catalogs will not be able to run if your PhoSim directory does not contain all of the SED files referenced in your instance catalog.** Most of these catalogs do not model actual astrophysical objects. They are created for simulation and testing purposes.

Physics command overrides

Built into PhoSim are several physics commands that override the default physics of the simulator. A full list is available here:
https://bitbucket.org/phosim/phosim_release/wiki/Physics%20Commands
These commands should be at the end of the command line used to run PhoSim and are essentially a shortcut that allow you to change the way the simulation runs without directly editing the instance catalog. For example, the "nobackground" command turns off cosmic rays and sets the dark sky brightness to approximately zero. Commands are invoked at the end of the command line as follows:

```
-c command_name
```

The command name corresponds to a **path** to a text file that specifies the changed settings. You can also create your own shortcut commands by creating a short text file specifying new values for each setting of interest. This will override the settings in your instance catalog.

Running PhoSim

When your instance catalog is complete, you are ready to run PhoSim. To start, open your command line and make sure you are in your PhoSim folder. Then type:

```
phosim instance_catalog.txt
```

If invoking physics override commands, type `-c command_name` at the end of the line. For example, when invoking the "no background" command with your instance catalog, you would type:

```
phosim instance_catalog.txt -c examples/nobackground
```

Then hit enter and the simulation will begin.

Running details

As PhoSim runs, it writes out what it is doing so you can follow along and make sure things are going according to plan. Here are the basics of the running process:

1. PhoSim sorts the object list from the instance catalog by chip. Based on input position, it determines which sources originate from each chip and groups them accordingly. Very bright objects may register as a source on multiple chips, but objects are generally sorted only by the position of their center.
2. PhoSim runs the simulation for each chip separately and consecutively. Each chip, and therefore each run of the simulation, will have separate output. If your catalog contains many objects spanning many chips, PhoSim will take much longer to run.
3. For each chip, PhoSim sorts object from brightest to dimmest and simulates photons for each set of objects of the same magnitude. A list of the number of objects at each magnitude, as well as the corresponding amount of simulated photons, will be written out.
4. PhoSim will produce an output for each chip and for each exposure of each chip. So, if `Nsnap = 2` or more, PhoSim will automatically run again and produce a new set of outputs for the same chip.
5. PhoSim produces a set of output images and transfers them to the folder titled "Output" in your PhoSim directory.

Running time

This process can take anywhere from minutes to hours, depending on magnitudes, exposure time, number of sources, and simulation settings. Many people run their simulations overnight and check their output in the morning. For some purposes, the "no background" command is very helpful for reducing running time.

Examples: Running PhoSim for one bright star with no background will produce output within a few minutes. Running PhoSim for 1 star with background will produce output within ~30 minutes. Running PhoSim for 10 bright stars with no background will produce output within ~10 minutes.

Channels (PhoSim 3.6):

This update allows for PhoSim to run for multiple chips at once, significantly decreasing run time for large data sets.

Output

PhoSim's output consists of a set of 17 FITS files. 16 of these are sections of one output image (LSST uses two columns of 8 CCDs), and the final file is a square image of the entire chip.

First, PhoSim outputs one 2000 x 500 image for each section of the chip, which together make up the total 4000 x 4000 pixel field.

The last output image is a 4000 x 4000 pixel “electron image,” which shows the image of the detected photons before they are processed by the simulated electronics of the detector. This image is not affected by nonlinearity and other electrical effects. While this kind of image isn’t possible to collect with a physical detector, it is useful for simulation purposes, as it can tell us what the effects of the simulated electronics are.

Each output image can be identified by its filename, which will indicate the filter and the chip that corresponds to the image, as well as the section of the chip, and whether the image is a “real” or an “electron” image.
For reference, here is an example of output files for one run of PhoSim:

lsst_a_99999999_f2_R22_S11_C00_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C01_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C02_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C03_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C04_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C05_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C06_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C07_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C10_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C11_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C12_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C13_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C14_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C15_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C16_E000.fits.gz
lsst_a_99999999_f2_R22_S11_C17_E000.fits.gz
lsst_e_99999999_f2_R22_S11_E000.fits.gz

Each piece of the file name gives a different piece of information. The first letter after LSST tells you the type of image, where “e” represents the electron image. The “f2” term here refers to the filter, where the ugrizy filters are labeled as f0-f5. The next two entries refer to the chip, and the C00 term is the particular section of the chip.

A single section of an amplifier image for one chip.

Example Run

```
Elles-MBP:phosim_35 elleojala$ ./phosim examples/star.txt -c examples/nobackground
------------------------------------------------------------------------------------------
Atmosphere Creator
------------------------------------------------------------------------------------------
Creating layer 0.
Creating layer 1.
Creating layer 2.
Creating layer 3.
Creating layer 4.
Creating layer 5.
Creating layer 6.
------------------------------------------------------------------------------------------
Instrument Configuration
------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------
Trim Catalog
------------------------------------------------------------------------------------------
Found 1 source(s) for chip R22_S11.
------------------------------------------------------------------------------------------
Photon Raytrace
------------------------------------------------------------------------------------------
Installing Universe.
Creating Air.
Generating Turbulence.
Building Optics.
Placing Obstructions.
Perturbing Design.
Electrifying Devices.
Contaminating Surfaces.
Diffracting.
------------------------------------------------------------------------------------------
Basic Setup
------------------------------------------------------------------------------------------
[outputdir] Output directory:                              .
[outputfilename] Output filename:                          lsst_e_99999999_f2_R22_S11_E000
[seddir] SED directory:
/Users/elleojala/Documents/LSST_Project/phosim_35/data/SEDs
[imagedir] Image directory:
/Users/elleojala/Documents/LSST_Project/phosim_35/data/images
[centroidfile] Output centroid file (0=no/1=yes):          0
[throughputfile] Output throughput file (0=no/1=yes):      0
[eventfile] Output event file (0=no/1=yes):                0
[eventFitsFileName] Output event Fits file name:           output.fits.gz
[bindir] Binary Directory:
/Users/elleojala/Documents/LSST_Project/phosim_35/bin
------------------------------------------------------------------------------------------
Module Switches
------------------------------------------------------------------------------------------
[telescopemode] Telescope mode (0=off/1=on):               1
[trackingmode] Tracking mode (0=off/1=on):                 1
[detectormode] Detector mode (0=off/1=on):                 1
[diffractionmode] Diffraction mode (0=off/1=on):           1
[zernikemode] Zernike mode (0=off/1=on):                   1
[straylight] Straylight mode (0=off/1=on):                 1
[aperturemode] Aperture mode (0=normal/1=on):              0
[ghostonly] Ghost-only mode (0=normal/1=on):               0
[saturation] Saturation mode (0=off/1=on):                 1
```

```
[blooming] Blooming mode (0=off/1=on):                     1
[atmosphericdispersion] Atmos. Dispersion (0=off/1=on):    1
[atmosphericdispcenter] Atmos. Disp. Ctr. Corr.:           1
[impurityvariation] Impurity Variation (0=off/1=on):       1
[fieldanisotropy] Field Anisotropy (0=off/1=on):           1
[fringing] Fringing (0=off/1=on):                          1
[deadlayer] Dead Layer (0=off/1=on):                       1
[chargediffusion] Charge Diffusion (0=off/1=on):           1
[photoelectric] Photoelectric (0=off/1=on):                1
[chargesharing] Charge Sharing (0=off/1=on):               1
[pixelerror] Pixel Error (0=off/1=on):                     1
[coatingmode] Coating Mode (0=off/1=on):                   1
[contaminationmode] Contamination Mode (0=off/1=on):       1
------------------------------------------------------------------------------------------
Telescope Operator and Bookkeeping
------------------------------------------------------------------------------------------
Pointing RA (degrees):                                     0
Pointing Dec (degrees):                                    0
Rotation Angle (rotSkyPos) (degrees):                      0
Angle of Spider (rotTelPos) (degrees):                     0
Zenith Angle (degrees):                                    1
Azimuthal Angle (degrees):                                 0
Filter (number starting with 0):                           2
Random seed:                                               1000
------------------------------------------------------------------------------------------
Instantaneous Instrument and Site Characteristics
------------------------------------------------------------------------------------------
[instrdir] Instrument & Site Directory:
/Users/elleojala/Documents/LSST_Project/phosim_35/data/lsst
[platescale] Plate Scale:                                  180000
[minr] Minimum aperture radius:                            2558
[maxr] Maximum aperture radius:                            4180
[chipid] Chip/Amplifier ID:                                R22_S11
[centerx] Chip center x (microns):                         0
[centery] Chip center y (microns):                         0
[pixelsx] Chip x pixels:                                   4000
[pixelsy] Chip y pixels:                                   4072
[minx] Minimum x pixel of amplifier:                       0
[maxx] Maximum x pixel of amplifier:                       3999
[miny] Minimum y pixel of amplifier:                       0
[maxy] Maximum y pixel of amplifier:                       4071
[pixelsize] Pixel Size (microns):                          10
[welldepth] Full well depth:                               100000
[nbulk] Bulk doping density:                               1.000000e+12
[nf] Front side doping density:                            -5.000000e+15
[nb] Back side doping density:                             0.000000e+00
[sf] Front side doping scale:                              1.000000e-02
[sb] Back side doping scale:                               2.500000e-03
[siliconthickness] Silicon Thickness (microns):            100.000000
[overdepbias] Over depletion bias (volts):                 -45.000000
[ccdtemp] CCD temperature (K):                             173.000000
[qevariation] QE variation:                                0.000000
[exptime] Exposure time (s):                               15.000000
[nsnap] Number of Snaps:                                   1
[shuttererror] Shutter error (s):                          0.000000
[timeoffset] Time offset (s):                              0.000000
[windjitter] Wind Jitter (degrees):                        1.767767
```

```
[rotationjitter] Rotation Jitter (arcseconds):            1.000000
[elevationjitter] Elevation Jitter (arcseconds):          0.020000
[azimuthjitter] Azimuthal Jitter (arcseconds):            0.020000
[izernike optic# zernike#] Zernike amplitude:
0.000000 0.000000 0.000000 0.000001 0.000046 -0.000068 -0.000029 -0.000023 -0.000025 0.000021
 0.000031 0.000001 0.000003 -0.000041 0.000015 -0.000005 -0.000005 0.000001 0.000002 -0.000002
0.000005
0.000000 0.000000 0.000000 0.000124 -0.000059 0.000070 -0.000090 0.000020 0.000159 -0.000024
 0.000048 -0.000035 -0.000025 -0.000046 -0.000016 -0.000035 -0.000040 0.000001 -0.000006
0.000037 -0.000016
0.000000 0.000000 0.000000 0.000001 0.000046 -0.000068 -0.000029 -0.000023 -0.000025 0.000021
 0.000031 0.000001 0.000003 -0.000041 0.000015 -0.000005 -0.000005 0.000001 0.000002 -0.000002
0.000005
0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
0.000000
0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
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0.000850 0.000120 0.000130 -0.000030 0.000050 0.000020 -0.000060 -0.000040 0.000050 -0.000010
 -0.000040 -0.000010 0.000010 -0.000000 0.000030 -0.000010 -0.000010 0.000020 -0.000010
-0.000020 -0.000020
[body optic# dof#] Body motion of optics:
2.497004 3.995291 -0.000000 0.002874 -0.000356 -0.000847
3.772535 5.386307 -0.000000 -0.000358 0.000717 -0.002061
2.497004 3.995291 -0.000000 0.002874 -0.000356 -0.000847
3.087039 3.161626 -0.000030 -0.002421 -0.008375 -0.004642
3.087039 3.161626 -0.000030 -0.002421 -0.008375 -0.004642
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3.087039 3.161626 -0.000030 -0.002421 -0.008375 -0.004642
0.000000 0.000000 0.000000 0.000000 0.000000 0.000000
[lascatprob] Large angle scattering probability:          0.135000
[toypsf] Toy PSF:                                         0.000000
[domeseeing] Dome seeing:                                 0.100000
[groundlevel] Ground level (m):                           2660.000000
```

```
[xtellocation] X Telescope location (m):                    0.000000
[ytellocation] Y Telescope location (m):                    0.000000
[latitude] Telescope latitude (degrees):                    -30.659999
[longitude] Telescope longitude (degrees):                  0.000000
[pressure] Air pressure (mmHg):                             520.000000
[waterpressure] Water vapor pressure (mmHg):                8.000000
[temperature] Ground Temperature (degrees C):               20.000000
[reldensity] Relative density:                              0.991943
[relo2] Relative O2 fraction:                               1.000112
[relh2o] Relative H2O fraction:                             1.195398
[aerosoltau] Aerosol optical depth:                         0.020000
[aerosolindex] Aerosol index:                               -1.280000
[relo3] Relative O3 fraction:                               0.895429
[natmospherefile] Number of atmosphere layers:              7
[seeing layer#] Seeing at 5000 Angstroms (arcsec):
0.071371 0.030509 0.074943 0.022959 0.082579 0.093844 0.230562
[wind layer#] Wind speed (m/s):
13.889783 48.865948 10.730749 7.753009 8.032717 8.490282 9.155691
[winddir layer#] Wind direction (degrees):
146.635856 353.084443 356.280508 348.826504 353.033572 361.365501 331.817120
[height layer#] Layer height (km):
16.000000 8.000000 4.000000 2.000000 1.000000 0.500000 0.020000
[outerscale layer#] Outer scale (m):
11.398241 14.286488 19.634047 25.204784 15.557941 15.034888 10.000000
[densityfluc layer#] Density fluctuation:
0.026458 0.026458 0.026458 0.026458 0.026458 0.026458 0.026458
[densitymean layer#] Density mean:
1.000000 1.000000 1.000000 1.000000 1.000000 1.000000 1.000000
[cloudmean layer#] Mean cloud extinction (km):
0.000000 0.045083 0.117146 0.000000 0.000000 0.000000 0.000000
[cloudvary layer#] Variation of cloud extinction (km):
0.000000 0.001621 0.002508 0.000000 0.000000 0.000000 0.000000
------------------------------------------------------------------------------------------
Number of Sources: 1
Photons: 3.21e+08   Flux: 4.12e-25 ergs/cm2/s
------------------------------------------------------------------------------------------
Photon Raytrace
commit none
------------------------------------------------------------------------------------------
------------------------------------------------------------------------------------------
Type                Sources         Photons  (Sat,Rem,Rej,Acc)%  Time (s)       Photons/s
------------------------------------------------------------------------------------------
Astrophysical m=13        1     320,500,468  (  5, 92,  1,  1)     151.34       2,117,672
------------------------------------------------------------------------------------------
Electron to ADC Image Converter
------------------------------------------------------------------------------------------
Reading out chip R22_S11 with amplifier chain R22_S11_C00
Reading out chip R22_S11 with amplifier chain R22_S11_C01
Reading out chip R22_S11 with amplifier chain R22_S11_C02
Reading out chip R22_S11 with amplifier chain R22_S11_C03
Reading out chip R22_S11 with amplifier chain R22_S11_C04
Reading out chip R22_S11 with amplifier chain R22_S11_C05
Reading out chip R22_S11 with amplifier chain R22_S11_C06
Reading out chip R22_S11 with amplifier chain R22_S11_C07
Reading out chip R22_S11 with amplifier chain R22_S11_C10
Reading out chip R22_S11 with amplifier chain R22_S11_C11
Reading out chip R22_S11 with amplifier chain R22_S11_C12
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Reading out chip R22_S11 with amplifier chain R22_S11_C13
Reading out chip R22_S11 with amplifier chain R22_S11_C14
Reading out chip R22_S11 with amplifier chain R22_S11_C15
Reading out chip R22_S11 with amplifier chain R22_S11_C16
Reading out chip R22_S11 with amplifier chain R22_S11_C17
Elles-MBP:phosim_35 elleojala$
```