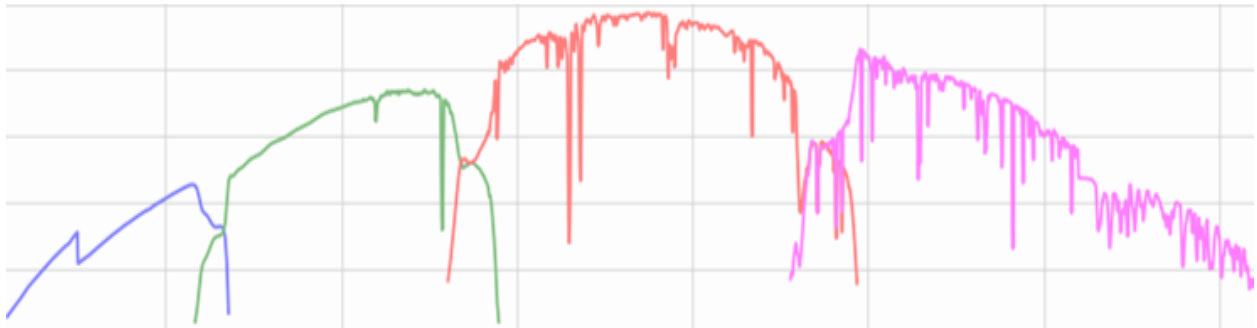# The NGPS
Observation Timeline Modeler
& Exposure Time Calculator

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Table of Contents

1 Introduction

This document describes the usage of and modeling behind the Observation Timeline Modeler (OTM) and Exposure Time Calculator (ETC) for the Next Generation Palomar Spectrograph (NGPS). These programs are intended to be used on their own by observers for planning purposes or via the NGPS Instrument Control Software (ICS) for automated updates to observing parameters.

The purpose of the OTM+ETC is twofold:
- Help the user plan and visualize the night's observations
- Compute optimized values for time-dependent or condition-dependent parameters: exposure time, slit width, slit angle

The output of the OTM includes predicted settings and conditions for each observation, including exposure start and end times. These are only predictions and **do not** drive the start/stop of exposures or slews of the telescope. The only **choices** that the OTM makes for the user – if requested – are the exposure times (duration), slit widths, and slit angles. Each OTM call makes the following assumptions:
- The user will attempt to observe all items on the target list in the order in which they are listed.
- Minimal delays between exposures or slews (configurable)
- The observing conditions for the night are constant.

As the night progresses, observing conditions and timing of exposures will deviate from the initial plan. The OTM should be periodically re-run to get updated predictions and parameters for remaining targets.

The OTM **does not** optimize the order of the target list – it assumes the target list is in the user's preferred order. The OTM flags targets that cause delays or are unobservable; it is up to the user to remove or change these so as to avoid wasting time on those targets. E.g. if the OTM predicts that an exposure is scheduled when the target has already set, it will cause the schedule to predict a delay for the rest of the night, missing all subsequent targets. This "naïve" behavior avoids creating nice-looking but undesirable schedules without the observer noticing.[1]

The OTM uses the ETC to automatically optimize exposure time and spectrograph slit width. If the ETC is not installed (or wanted), these parameters must be explicitly set by the user for each target.

The OTM is written in Python3 (NGPS uses Python3.9) and uses the astropy[2] and scipy packages. The ETC is written in Python3 (tested with 3.9, 3.10.4), and uses the astropy (version >= 5.1) and synphot[3] (version >=1.1.2) packages. All parameters specific to NGPS have been organized in config files (OTM_config.py, ETC_config.py), hopefully making it straightforward to adapt these for other spectrographs. The config files are not specially formatted – it is just more Python code where parameters and paths are defined. Example parameters in the OTM config file are pointing limits, slew speeds, and detector readout times. The ETC config file contains e.g. data on instrument throughputs, dispersion scale, and telescope size.

2   Basic Usage

2.1   NGPS Observing and Planning GUIs

The OTM is invoked by the NGPS Observation or Planning GUIs each time the green *Accept* button is clicked. For usage without the ETC, all required input fields are located on the target table to the left (blue column headers), the Observation tab to the right, and the Planning pane on the right. The OTM will not alter the user's input parameters.

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[1] Methods to optimize the target order for the user (a non-trivial problem) are being investigated and may be available as a future feature.

[2] https://docs.astropy.org/

[3] https://synphot.readthedocs.io

There are 3 parameters that users can use to request parameters be calculated for them:

- **Requested Slit Angle**: The position angle of the slit (long direction) in degrees, defined as East over North. Since the slit has 180 deg symmetry, the OTM may use an equivalent angle to minimize slew time. To use the target's parallactic angle, enter "PA".
- **Requested Slit Width**: Slit width[4] in arcsec. Use the "SET" keyword to set this to a fixed value, e.g. "SET 1.3".
- **Requested Exptime**: Exposure time in seconds. Use the "SET" keyword to set this to a fixed value, e.g. "SET 450".

Using the "SET" keyword should simply transfer these values to the Calculated Slit Width and Exptime columns on the target table when the OTM runs. As explained below, other keywords can be used to optimize these values using the ETC.

Once the OTM runs, it populates fields in the target table (grey column headers) and *Plan* tab. Parameter descriptions are in Section 3.2. A timeline displaying the predicted exposures times and airmasses of all targets will appear.

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[4] The image slicer triples the collection area defined by this width.

Users should check the timeline for delayed or failed targets and then modify the target list or other parameters if a different result is needed. Although we encourage users to consider the OTM results while planning the evening's activities, you are free to ignore the results including the timeline. With the exception of the slit angle, slit width, and exposure time, none of the OTM-computed values will affect the operation of the telescope or instrument.

The GUIs allow users to set up their target list using a CSV file. Descriptions of the CSV file columns, which map to fields in the GUIs, are described in Section 3.2.

2.2   Using the ETC

The ETC computes the *Calculated Exptime*, *Calculated Slit width,* and/or *OTMSNR* columns depending on the keywords used in the *Requested Slit width* and *Calculated Exptime* columns. If both use the "SET" keyword, the ETC will predict the target SNR (defined as the average SNR per wavelength bin in the detector spectral direction) in *OTMSNR*. If *Requested Exptime* uses the "SNR" keyword to fix the SNR, then the ETC is used to compute *Calculated Exptime*. *Calculated slit width* can also be optimized using keywords for *Requested slit width* (see below).

The ETC accounts for CCD binning as set in the Observation tab. Parameters for airmass and sky background are obtained from fields populated by the OTM. Seeing at zenith is set in the Planning pane in the upper right and extrapolated to the position of the target at the expected observation time.

For the ETC-calculated values to be sensible, additional information must be provided in the ETC tab to the right. If these values are left to their defaults, the calculations will be erroneous. If not using the ETC to optimize the slit width or exposure time, *OTMSNR* may be calculated regardless, but it should be ignored if values in the ETC tab have not been deliberately set.

Each of these fields correspond to an argument described in Section 3.3: wrange, channel, mag, magsystem, magfilter. The SRCMODEL parameters field can be used to model the source as described in 4.5. Unlike the other fields, *SRCMODEL* uses the "-keyword value" syntax used at the command line. It is generally OK to leave this field in the default state – it will not affect the results much unless the wavelength range is relatively large and the target is being normalized in a filter with little overlap to the channel.

2.3   Errors

The OTM will attempt to catch errors and print standardized error messages that can be easily parsed by the ICS/GUI. Some lengthy Python traceback info may be printed below the standardized error message.

A common error is that no targets are predicted to be completed. This indicates that the target list is poorly matched to the start time and date of the observation. Try changing the start time.

ERROR, RUN, <row index>, <message>
Runtime errors – caught during the main execution of the script. Also a catch-all for unexpected errors. If caught while looping over the target list, this will include the row index of the target in the list.

ERROR, CMD, <message>
Command line errors – denotes a problem with the command string executing the program

ERROR, CSV, <column name>, <row index>, <message>
CSV file errors – denotes a problem with the CSV file format. Attempts to pinpoint the column and row where the problem is found.

The first target in the CSV file has index 0. If a negative row index is printed, it denotes a problem encountered before or after parsing and checking the file.

NB. The primary output of the OTM is a CSV file with the results, so the calling script should check whether this has in fact been produced/updated.

3   OTM Inputs

3.1   Command Line

Skip to section 3.2 if only using the OTM through one of the NGPS GUIs. An example use of the OTM at the command line:

./OTM.py target_list.csv 2022-01-01T03:00:00.000 -seeing 1.1 500

Where the inputs consist of a list of targets, the exposure start time of the first target, and expected seeing (arcsec) at a reference wavelength (nm).

Use the -h option to display a help message with a brief description of the parameters, or keep reading here. The OTM will automatically invoke the ETC as needed, similar to the GUI usage above.

3.1.1   Required arguments

Usage format:

./OTM.py FILE START -seeing SEEING PIVOT [options]

FILE (str)
The 1st argument is the path to a CSV file containing a list of targets.

START (str)
The 2nd argument is the UTC start time of the first observation in the target list. We assume that target is already acquired, so it is the exposure start time. This is a string that can be converted to UTC time by astropy: YYYY-MM-DDThh:mm:ss.sss

-seeing SEEING PIVOT (float, float)
Next the user specifies the seeing at zenith in arcsec. Since seeing varies slightly with wavelength ($\sim\lambda^{0.2}$), the single seeing value must be defined at a pivot wavelength in nm. Note this defines seeing for the **entire night**, which is unrealistic, hence the need to periodically re-run the OTM with update values.

Thus, in the example:
./OTM.py target_list.csv 2022-01-01T03:00:00.000 -seeing 1.1 500 [options]

…we will be stepping through the file target_list.csv, assuming the first exposure starts at 3:00 UTC on 2022-01-01, and assuming the seeing at zenith is 1.1" for 500nm.

3.1.2   Optional Arguments
These arguments may be omitted.

-h, --help
Show the help message and exit

-out (str)
Output path/filename of the OTM results (a CSV file).

-airmass_max (float > 1)
Wait to observe targets until airmass is below this limit. Used for blank entries in the airmass_max column.

-alt_twilight (float < 0)
Sun altitude (degrees) defining twilight observing limit.

3.1.3   More Optional Arguments
Less likely to be used by non-developers

-forceSNR
Always use the ETC to calculate signal-to-noise for each target. By default, SNR is not calculated when exposure time and slit width are fixed.

-casclamp
Include 18s delay to unclamp cassegrain ring during slews. NOT IMPLEMENTED

-saveall
Copy entire input table and intermediate results to the output CSV file.

-check
Pretty print the input target list CSV file, check that all inputs are valid, then stop. Only useful at the command line. Problems with the input file will be flagged and highlighted. Use this to debug your input file without running the whole OTM.

-debug
Print things. Enter interactive mode before exiting.

-verbose
Print things.

3.2 Input table format

The input file is a CSV file with a header line and each subsequent line denoting the parameters of a single exposure of a target. Repeated exposures of a target must be explicitly entered as repeated lines. The OTM assumes that the targets are observed in the order provided and that each target is observed as soon as possible after the previous one. If the OTM determines a target will not be observable at the predicted start time, it will be flagged. It is up to the user to check the output of the OTM and iterate on the target order until an acceptable result is returned.

The order of the columns does not matter as long as the header line and data are consistent. The first 11 columns shown below are required and may not contain blanks except for airmass_max. The slitwidth and exptime columns may contain a keyword that requests an ETC calculation for that row (see below). In that case, the remaining columns (all ETC-specific) must be fully populated in that line, with the exception of srcmodel, which can be blank. Unrecognized column headers are allowed but will be ignored.

name	RA	DECL	epoch	binspect	binspat	ccdmode	slitangle	slitwidth	exptime	airmass_max	wrange	channel	mag	magsystem	magfilter	srcmodel
ZTF22aajmnru	-00:42:57.35	+41:16:18.53	J2000	1	1	default	PA	SET 1	SNR 7	3	600 620	R	20	AB	user	
ZTF22aajmnru	-00:42:57.35	+41:16:18.53	J2000	1	1	default	PA	SET 1	SNR 7	3	600 620	R	20	AB	user	
ZTF22aajmnru	-00:42:57.35	+41:16:18.53	J2000	1	1	default	PA	SET 1	SNR 7	3	600 620	R	20	AB	user	
ZTF22aaheakp	06:54:07.43	+69:38:38.92	J2000	2	3	default	PA	SET 1	SNR 7	3	800 820	I	20.3	AB	user	-model blackbody 6000 -z 1
ZTF22aaheakp	06:54:07.43	+69:38:38.92	J2000	2	3	default	PA	SET 1	SNR 7	3	800 820	I	20.3	AB	user	-model blackbody 6000 -z 1
ZTF22aaheakp	06:54:07.43	+69:38:38.92	J2000	2	3	default	PA	SET 1	SNR 7	3	800 820	I	20.3	AB	user	-model blackbody 6000 -z 1
ZTF20ackgfep	07:18:42.74	+51:54:08.74	J2000	1	1	default	PA	PSF 97	SET 500	3	500 510	G	19	AB	user	
ZTF20ackgfep	07:18:42.74	+51:54:08.74	J2000	1	1	default	PA	PSF 97	SET 500	3	500 510	G	19	AB	user	

name (str)
The target name is any alphanumeric string. Special target names are reserved in order to invoke calibration, dark, and bias frames. These reserved names are: dark, bias, calib

RA (str)
Right ascension is formatted as a sexagesimal string, "HH:MM:SS.S" where the hour-minute-second separator may be either a colon or a space. range is >= 0 (00:00:00.0) and <= 24 (24:00:00.0).

DECL (str)
Declination is formatted as a sexagesimal string, "±DD:MM:SS" where the degree-minute-second separator may be either a colon or a space. Acceptable range is >= -90 (-90:00:00) and <= +90 (+90:00:00). The + sign is optional; if omitted then the sign will be assumed to be positive.

airmass_max (float > 1)
Wait to observe targets until airmass is below this limit. If blank, defaults to value set by -airmass_max command line option.

binspect (int > 0)

Assume that the detector bins the signal along the dispersion/spectral axis. Arguments must be whole numbers (default 1). Typically used to reduce detector read noise but can reduce resolution. See Table 1 for pixel scales.

binspat (int > 0)
Assume that the detector bins the signal along the spatial axis. Arguments must be whole numbers (default 1). Typically used to reduce detector read noise but can reduce resolution. See Table 1 for pixel scales.

ccdmode (str)
TBD – something that denotes the readout speed, amps, framestore, etc.

slitangle (float or "PA")
Position angle of the slit in degrees (relative to North Celestial Pole, increasing with RA). If the string "PA" is used, the OTM will use the target's parallactic angle. The PA is time-dependent, so the OTM predicts the value at the midpoint of the exposure. The OTM should be re-run to refresh PA values, but the PA will be accurate if the exposure starts within 5 min of the OTM's predicted start time.

Since the spectrograph slit has 180 deg symmetry and since the slitangle range spans more than 360 deg, the OTM will choose an equivalent angle that minimizes slew times.

slitwidth (str float)
Slit width is formatted as a string, consisting of a keyword and a floating point number. Keywords other than SET will invoke the ETC to compute slitwidth. Examples:

- SET X: sets slit width to a fixed value X in arcsec (0 < X <= 10). Example: SET 1.1
- LOSS X: yields an X% slit loss of the PSF for the slicer (3x slit width). Example: LOSS 3. The "SNR" keyword below improves on this mode.
- RES X: yields a resolution $R=\lambda/d\lambda=X$. Example: RES 2000. If X is less than the minimum resolution set by the PSF for a point source, the slit will be set to yield R=X for an extended source.
- SNR X: yields a signal-to-noise ratio that is X% of the maximum possible SNR (combining all slices). Sacrificing a small amount of SNR like "SNR 95" can significantly improve resolution.
- AUTO: Equivalent to "SNR 95" which we find to be a useful rule of thumb for achieving a balance between SNR and R.

exptime (str float)
Exposure time is a value formatted as a string, consisting of a keyword and a floating point number. Applies to all spectrograph cameras. Keywords other than SET will invoke the ETC to compute exptime. Examples:

- SET X ; set to a fixed value in seconds (0.001 <= X <= 16,777.216). Example: SET 600
- SNR X ; compute exposure time that will achieve SNR=X. Example: SNR 10

3.3   ETC-required columns

The columns below are only needed if using the ETC. With the exception of srcmodel, these parameters map exactly to the ETC parameters of the same name (cf. ETC manual).

wrange (float float)

A pair of floats denoting the minimum and maximum wavelengths for which to compute SNR for exptime and/or slitwidth calculations. Both wavelengths must fall within the range of channel to avoid an error (see Section 8 for wavelength ranges). SNR will be calculated for a whole number of spectral bins on the detector. The inputs are rounded up (i.e. to a wider range) to a whole number of bins.

channel {U,G,R,I}

A single spectrograph channel to use for SNR calculations. We have not implemented combining signals from ranges where two channel bandpasses overlap, which requires a well-defined procedure for doing so.

mag (float)

Source magnitude (observed at top of atmosphere).

magsystem (str)

String denoting the reference system (AB or VEGA) for the source magnitude.

magfilter (str)

String denoting the filter for the source magnitude. The filter can be any Johnson filter (UBVRIJK), or set the filter to "user" to normalize to a top-hat bandpass filter corresponding to the wrange input. For small wrange, this makes the result insensitive to the model.

srcmodel (str) -- optional

Here the user may *optionally* enter a string to model the spectrum of the source. The string corresponds to the Additional Source Parameters of the ETC and must be entered in the same format as one would enter them at the ETC command line (See Section 4.5). You may also add -hires to this field to have the ETC perform a high-resolution calculation, which takes more time and may only be necessary if calculating SNR for a sharp spectral feature.

If no srcmodel is provided, the ETC defaults to "-model constant", which assumes a spectrum with a flat flux density normalized by mag. This should be good enough if the range in wrange is small and the "user" filter is used in magfilter, which normalizes the source in the same band as the SNR measurement. If using a large wavelength range or if specifying the normalization in

a different filter than the measurement, then the ETC's SNR calculation will be sensitive to the shape of the source model.

Examples:

-srcmodel blackbody 6000 -extmodel lmcavg -E_BV 1
Model a 6000K blackbody spectrum with extinction law given by the LMC average and selective extinction E(B-V) = 1.

-srcmodel template elliptical_001 -z 2
Model an elliptical galaxy spectrum at redshift z=2.

4   Command Line ETC

An example use of the ETC at the command line:

./ETC_main.py G 500 510 SNR 10 -slit SET .5 -seeing 1 500 -airmass 1 -skymag 21.4 -mag 18. -magsystem AB –magfilter user

The command line takes a combination of positional arguments and unordered keyword arguments. All of the keyword options shown here are required parameters; this format was chosen to increase legibility of long input strings. The order of keyword options at the command line does not matter. All of the required command line parameters map to columns in the CSV with the same names, detailed above (Section 3.3), that the OTM needs to run the ETC.

When used at the command line, the ETC prints its results to STDOUT. Use the -h option to display a help message with a brief description of the parameters.

4.1   Required Positional Arguments

channel {U,G,R,I}
The 1st argument selects a single spectrograph channel to use for the SNR calculation.

wrange (float float)
The 2nd argument set is a pair of floats denoting the minimum and maximum wavelengths for which to compute SNR.

{SNR, EXPTIME}
Which parameter to fix: SNR or exposure time. The ETC will calculate a value for the parameter not chosen.

ETCfixed (float)

The final positional parameter is the value of SNR or EXPTIME (seconds), whichever is fixed. SNR is per wavelength bin, averaged over the chosen wavelength range.

Thus, in the example: ./ETC.py G 500 510 SNR 10 [options]

...we are computing the exposure time that yields an average SNR of 10 from 500-510nm in the G channel.

Whereas in: ./ETC.py G 500 510 EXPTIME 60 [options]

...we are computing the signal to noise ratio for an exposure time of 60 seconds.

4.2   Optional Arguments
These arguments may be omitted.

-h, --help
Show the help message and exit

-binspect BINSPECT (int > 0)
Bin the detector signal along the dispersion/spectral axis.

-binspat BINSPAT (int > 0)
Bin the detector signal along the spatial axis.

-fastSNR
By default, the ETC assumes a spectrum is extracted by fitting a spatial profile, which is dominated by seeing. This is done for each of the 3 slicer images, and we assume these are combined with proper weighting to optimize total SNR. The –fastSNR option assumes the user will instead extract the spectrum simply by summing the signal in the 2 brightest pixels from the center slit. The ETC samples the spatial PSF by placing the centroid on the boundary between 2 pixels, which simplifies computations.

-noslicer
Assume we only use flux from the center slit, ignoring the side slices.

-plotSNR
Plot SNR vs. wavelength for the solution

-plotdiag
Make additional diagnostic plots

4.3   REQUIRED Observation conditions

-slitwidth MODE (str) VALUE(float)
The slit width of the spectrograph can be specified explicitly or calculated to satisfy some condition. If MODE="SET", then VALUE is the spectrograph slit width in arcsec. The slicer collects light from 3 times this width. See Figure 1 for slit loss data. Other modes (LOSS, RES, SNR, AUTO) described above.

-seeing SEEING PIVOT (float float)
Seeing FWHM (arcsec) defined at a pivot wavelength (nm). The pivot is required since the model accounts for seeing slowly varying with wavelength.

-airmass AIRMASS (float)
Airmass (dimensionless); airmass=1 at zenith.

-skymag SKYMAG (float)
Sky brightness in magnitude per $arcsec^2$ (VEGA, johnson_v)

4.4   REQUIRED Source parameters

-mag MAG (float)
Source magnitude (observed at top of atmosphere)

-magsystem MAGSYSTEM (str)
Reference system (AB, VEGA) for source magnitude.

-magfilter (str)
Johnson filter (UBVRIJK) to define source magnitude.

4.5   Additional Parameters for Source Modeling:

-model {constant, blackbody, template} [args]
Astronomical source model type. The additional arguments depend on the 1st argument:
Constant (default): constant flux vs. wavelength; no additional arguments
Blackbody: float; temperature in Kelvin (float); ex. blackbody 6000
Template: string; template name (see Section 4.6); ex. template elliptical_001

-z Z (float)
Redshift. Default = 0.

-E_BV E_BV (float)
Selective Extinction E(B-V); default=0

-extmodel EXTMODEL (str)

Extinction model; default is "mwavg". The model options below (and the table itself) are taken from the [synphot reddening module](#).[5]

Name	Description	Reference
mwavg	Milky Way Diffuse, R(V)=3.1	Cardelli et al. (1989)
mwdense	Milky Way Dense, R(V)=5.0	
mwrv21	Milky Way CCM, R(V)=2.1	
mwrv4	Milky Way CCM, R(V)=4.0	
lmc30dor	LMC Supershell, R(V)=2.76	Gordon et al. (2003)
lmcavg	LMC Average, R(V)=3.41	
smcbar	SMC Bar, R(V)=2.74	
xgalsb	Starburst, R(V)=4.0 (attenuation law)	Calzetti et al. (2000)

4.6   ETC Source Template Catalogs

Spectral templates were downloaded as FITS files from Space Telescope Institute's astronomical catalogs for the Hubble Space Telescope[6]. To use a template, specify a filename from the tables below (omit the ".fits" extension). Please follow the links for information about the models.

Example: -srcmodel template spiral_001

current_calspec – composite stellar spectra that are flux standards on the HST system		
agk_81d266_stisnic_007	gd153_mod_011	sun_reference_stis_002
alpha_lyr_stis_010	gd71_mod_011	vb8_stiswfcnic_003
bd_17d4708_stisnic_007	grw_70d5824_stiswfcnic_003	wd0308_565_mod_006
bd_28d4211_stis_005	hz21_stis_006	wd0947_857_stis_005
bd_75d325_stis_005	hz44_stis_006	wd1057_719_mod_006
feige110_stisnic_008	lds749b_mod_007	wd1657_343_mod_007
feige34_stis_006	p330e_stiswfcnic_003	
g191b2b_mod_011	sirius_mod_004	

nonstellar – nebulae, galaxies, quasars[7]		
05189m2524_fullsed_001	ngc1068_template_001	sb6_kinney_fuv_001
12112p0305_fullsed_001	ngc6240_fullsed_001	sbc_cb2004a_001
14348m1447_fullsed_001	orion_001	sbc_cww_001

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[5] Last updated 2022-05-24

[6] https://www.stsci.edu/hst/instrumentation/reference-data-for-calibration-and-tools/astronomical-catalogs

[7] Oh my!

15250p3609_fullsed_001	orion_smooth_001	scd_cb2004a_001
22491m1808_fullsed_001	pn_nebula_only_smooth	spiral_001
arp220_fullsed_001	pn_smooth_001	ssp_25myr_z008_001
el_cb2004a_001	qso_template_001	ssp_5myr_z008_001
el_cww_fuv_001	s0_fuv_1_001	tau06_z02_1015_190_001
elliptical_001	sa_fuv_1_001	tau06_z02_12000_000_001
hrc_dqea_001	sb1_kinney_fuv_001	tau06_z02_2500_000_001
im_cb2004a_001	sb2_b2004a_001	tau06_z02_4500_000_001
m82_fullsed_001	sb2_kinney_fuv_001	tau06_z02_5000_000_001
mrk1014_fullsed_001	sb3_b2004a_001	tau06_z02_6000_000_001
mrk231_fullsed_001	sb3_kinney_fuv_001	tau06_z02_8000_000_001
mrk273_fullsed_001	sb4_kinney_fuv_001	ugc5101_fullsed_001
mrk463_fullsed_001	sb5_kinney_fuv_001	ugc5101_fullsed_002

novae		
kilonova_transient	sneiax_plasticc_transient	sneii_fast_transient
sne91bg_plasticc_transient	sneib_transient	sneii_slow_transient
sneia_salt2_transient		

5   OTM Results

When using the NGPS GUIs, the OTM will populate fields in the target table and detail pane with its results (these are not manually editable). From the command line, the OTM produces an output CSV file with the same information.

5.1   Output CSV file

The output file will have a header line and one line for each line in the input file (in the same order). A line may contain blanks if the exposure for that line is predicted to be invalid. Here we define the parameters in each column/field:

- i: int; counter for unique targets. It increments only when a line contains a different target name than the previous line.
- OTMpa: float; predicted parallactic angle in degrees (computed regardless of whether PA is used for the target)
- OTMslitangle: float; predicted slit position angle (deg) which satisfies user input and minimizes slew time. May differ by 180 deg from slitangle input.
- OTMcass: float; predicted setting for the cassegrain angle (deg) to be sent to TCS. Accounts for rotation offset between slit and cass ring.
- OTMflag: string; Flag for predicted problems with the exposure

- OTMwait: float; predicted wait time (minutes) after previous exposure until present target becomes observable
- OTMslewgo: string; Start time of slew to target (YYYY-MM-DDThh:mm:ss.sss)
- OTMlast: string; pointing degree of freedom with longest slew time
- OTMslew: float; slew time in seconds
- OTMdead: float; time between start of exposure and end of previous exposure
- OTMstart: string; exposure start time (YYYY-MM-DDThh:mm:ss.sss)
- OTMend: string; exposure end time (YYYY-MM-DDThh:mm:ss.sss)
- OTMairmass_start: float; predicted airmass (dimensionless) at exposure start
- OTMairmass_end: float; predicted airmass (dimensionless) at exposure end
- OTMsky: float; predicted sky background at the target in mag/arcsec^2
- OTMslitwidth: float; predicted slit width in arcsec. This is either an ETC result or a copy of the user's input if explicitly set.
- OTMexptime: float; predicted exposure time in seconds. This is either an ETC result or a copy of the user's input if explicitly set.
- OTMSNR: float; predicted SNR. This is either an ETC result or a copy of the user's input if explicitly set.
- OTMres: float; predicted resolution R=λ/dλ, where dλ is the larger of the line-spread-function width or the spectral bin width (accounting for CCD binning)
- OTMmoon: Angular separation between target and the Moon

5.2   Flags

The OTMflag field contains codes to warn the user about a problem (not necessarily an error) with a given line/observation. A flag may mean the observation will be delayed (see OTMwait field). We generally want to construct the input target list to minimize flags.

- -0 -- Problem at the beginning of the exposure (assumes a delay)
- -1 -- Problem at the end of the exposure
- ALT -- Target's altitude is out of range
- AIR -- Target's airmass out of range (set by user)
- HA -- Target's hour angle is out of range
- DAY -- Observation is scheduled during daylight
- EXPT -- Exposure time longer than 1000 seconds. Consider multiple shorter exposures.
- SKY -- The sky background prediction is unreliable (expected at airmass>3)

Time-independent range violations (e.g. declination) are caught when the input is loaded. The flags above require the full program to run.

Example: "ALT-0 EXPT" Target's altitude is predicted to be out of range when it is time to slew to it. This triggers a delay until the pointing is valid. The target has a long exposure time, possibly due to being observed at low altitude (high airmass).

Example: "HA-0 DAY-1" Target's hour angle is predicted to be out of range when it is time to slew to it. This triggers a delay until the pointing is valid. The exposure's predicted end time is during daylight.

6 OTM Calculation Model

Here we describe the steps and assumptions of the OTM calculations, presented in an order that approximates the logic of the code. This is mostly qualitative – we want to give users a sense of the code's features and limitations.

Startup

Various Python packages are imported. The command line arguments are parsed and checked for validity. The input CSV file is loaded and checked for validity, including data types and ranges. If there's a problem with the input file, it gets printed to STDOUT with messages to help the user pinpoint problems. Not all problems may be caught on the first pass.

If the OTM's -check option is used, the program exits here.

If the OTM detects that a line in the input file requires the ETC, the ETC module is imported. ETC-specific columns will also be checked for validity.

Sunrise

Starting from the user's start time, we compute the length of time until the next sunrise (end of astronomical twilight: Sun altitude > 12 deg). If the sky is not dark at the start time, it is moved forward in time to twilight, and the first target will show a flag and a delay.

THE MAIN LOOP

Next, we step through the lines of the input target list. The first target is assumed to be already acquired at the start time. The start time is thus the expected or actual start time of the first target's exposure. As we progress through the observations, we wind the clock forward.

Check Previous Flags

If the current line is a copy of the previous line, and if the previous line had a flag at the end of the exposure, we assume the current target will have the same flag. For example, if the target sets (invalid altitude) before the previous exposure completes, and if the current exposure is a repeat of the previous one, it is flagged.

Check new pointing

Check that our new pointing is valid. If not, we wind the clock forward until the target can be observed or the night is over. If the target cannot be observed, it is flagged along with all subsequent targets, and the program quits. If the target list is poorly designed, this step may introduce large delays. *The OTM does NOT reorder targets for the user – it only predicts a timeline given the target list and conditions.*

Slew Time

Compute the slew time to the new pointing by comparing to the previous pointing (slew time for 1st target is 0). Pointing includes the Cassegrain angle – if the parallactic angle is required, it is first predicted at the time of slewing and then adjusted to the midpoint of the exposure once that is computed. The slew time calculation is based on a constant-acceleration model for each degree of freedom: hour angle, declination, cass angle, dome rotation (azimuth). Since these move independently, the slew time is set by the degree of freedom that takes the longest (including settling time). Slew parameters can be found in OTM_config.py. For very short slews or multiple observations of the same target, the limiting element may in fact be the spectrograph slit width or the detector readout times.

The dome has no limits on rotation angle and will take the shortest route to the new pointing. Due to the 180 deg symmetry of the slit, there will be multiple accessible Cassegrain angles which satisfy the user's input. The OTM will select the casangle closest to zero, provided that the time to move there is less than other overheads. Otherwise it will select a position to minimize the slew time.

We wind the clock forward by the slew time starting from the end time of the previous exposure. The detectors can complete reading out during the slew, so the read time is absorbed into the slew time unless the slew is very short (or multiple exposures of the same target). Read time may vary based on the CCD mode chosen (e.g. whether using on-chip binning or framestore).

There is a parameter in OTM_config.py to allow for a fixed delay before slews, corresponding to some operator delay (e.g. voice confirmation).

Exposure time

Now that we know the time of arrival at the next pointing, we can predict the airmass, seeing, and sky brightness, which are needed for the ETC to compute the exposure time (and slit width if desired). See the ETC manual for details of the ETC calculations.

If not using the ETC, the exposure time is simply set by the user's input, and the clock is wound forward.

There is a parameter in OTM_config.py to allow for a fixed delay before exposures, corresponding to some operator delay (e.g. final checks).

Check pointing again

We check to make sure the target has a valid pointing at the end of the exposure, e.g. in case it sets or the sky is no longer dark. If the exposure cannot be completed acceptably with the given parameters, the target is flagged, but the NGPS Observation Sequencer will attempt to do the exposure anyway unless the user makes a change.

Proceed to next target

Repeat until finished!

The user will be able to see from the output (OTMflag) whether any targets had delays or could not be observed at all. It is up to the user to rearrange the input file to get a better result.

7   ETC Calculation Model

Here we describe the steps and assumptions of the SNR calculation, presented in an order that approximates the logic of the code. This is mostly qualitative – we want to give users a sense of the code's features and limitations.

Startup
Various Python packages are imported. This is by far the most time-consuming step (~1 second on the NGPS computer). The command line arguments are parsed and checked for validity.

Source model
Depending on the model, a source spectrum is either generated from a function or imported from a template file. Models are loaded as flux densities (photons/s/cm2/Å). Astrophysical modifications (redshift, extinction, etc.) are applied.

Normalization
Next the source spectrum is normalized per the user input (magnitude, bandpass, reference system). If Vega mag is selected, the ETC integrates over the synphot Vega model to obtain the normalization. The source is now normalized as it would be observed at the top of Earth's atmosphere.

Sky Background
A model for the sky background spectrum is loaded – this is currently a 1D function downloaded from Gemini Observatory[8]. We anticipate using data from Palomar to construct a more sophisticated model that depends on coordinates, moon phase, and weather. For now, the Gemini model is converted to a constant flux per spatial pixel and normalized per the user input (reference and bandpass are hardcoded to Vega mag, Johnson V).

Throughput
Efficiency curves for the various instrument components are loaded and multiplied together to obtain throughput, with separate throughputs for the center and side paths of the image slicer. For point sources, the fraction of the PSF transmitted through each path is calculated as a function of wavelength and appended to the throughputs. This computation projects a seeing-limited PSF (2D Moffat function) onto rectangular slit sections. It is wavelength dependent since seeing is a weak function of wavelength, w:

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[8] http://www.gemini.edu/observing/telescopes-and-sites/sites#OptSky

$$S (w) = S\_0 * (w/w\_0)**1/5$$

Where S is the full width at half max (FWHM) of the seeing profile, S_0 is the seeing FWHM at the pivot (user input), and w_0 is the pivot wavelength (user input).

Atmosphere
A model for the atmospheric extinction vs. wavelength at Palomar is loaded and scaled by airmass (user input) to get a transmission:

$$T(w) = T\_0(w) ** A$$

where T_0 is the model and A is airmass (user input). This transmission is included in the product of the instrument throughputs.

Observed spectrum – dispersion direction
The source and sky spectra are multiplied by the throughputs separately for each slicer path. At this time the sky background is NOT modulated by atmospheric extinction, i.e. we assume the user inputs the *observed* background in mags/arcsec^2.

The resulting spectra are then convolved with a line spread function (LSF), which will broaden any sharp features but should have little effect on a continuum. For each spectrograph channel, we assume that lines from a calibration lamp are given by a gaussian with a single width. We then convolve that gaussian with an approximation of the seeing-limited PSF projected onto the slit – here we take the PSF to be a gaussian with FWHM given by the seeing at the center of the channel bandpass. The resulting composite kernel is then convolved with the source and sky spectra (this requires upsampling to smaller wavelength bins beforehand and resampling at the wavelength bin centers afterwards). One should find that the LSF width is dominated by the width of the calibration lines as the slit width → 0, and the LSF width is dominated by seeing as the slit width → ∞.

Limitations: LSF is approximated using gaussians and assumed to be constant with wavelength for each channel. LSF for center and sides of slicer are identical. LSF does not vary in the spatial direction.

Projection onto focal plane
We need to know how the signal is distributed on the focal plane in the spatial direction in order to compute the relative signal and noise in each detector pixel. Generally, SNR is higher when signal is concentrated into fewer pixels, each of which includes background and read noise.

For point sources, we calculate the profile of the spectrum in the spatial direction by integrating the PSF over the slicer sections (dispersion direction) and over detector pixels (spatial direction). We assume the source is exactly centered on the slit and that the peak lies on a

pixel boundary in the spatial direction. The spatial integrals account for detector binning.
These profiles are normalized so that summing over one column (spatial sum) equals unity.

Below are example profiles for a blackbody source in the G channel, with 2x2 pixel binning,
shown for the center (top) and a side slice (bottom). A simulated noiseless background has
been added for illustration.
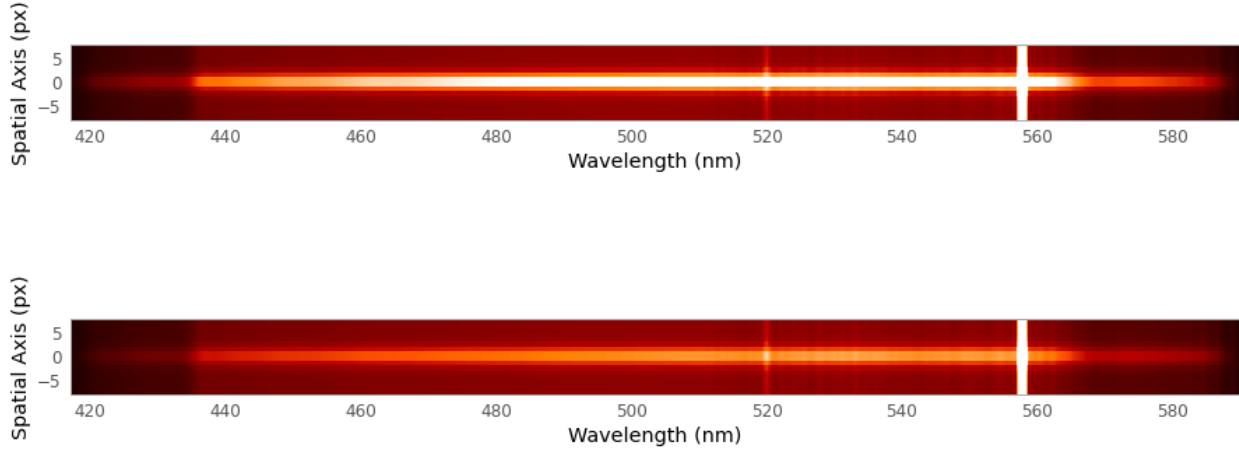
For each wavelength bin, we then compute a **sharpness** parameter, where 1/sharpness is the
effective size (height) of the spatial profile in pixels.

SNR calculation
The source and sky spectra are converted from flux densities to detected counts/s/bin (bin is a
pixel in the dispersion direction) using the telescope and instrument properties in the config file
(synphot makes this very easy). Dark current rates are added to the sky rate to obtain total
background. Both source and sky are scaled by exposure time, which is either given by the user
input or by a variable being looped over to find the value that obtains the requested SNR.

The background given in counts/pixel is taken to be the background contribution to shot noise
variance in each detector pixel. A single read noise variance is added to all pixels, accounting
for detector binning.

We then compute the SNR for each wavelength bin according to[9]:

$$SNR = \frac{R_{object} \cdot t}{\sqrt{R_{object} \cdot t + \dfrac{readnoise^2 + P_{dark} \cdot t + P_{sky} \cdot t + P_{background} \cdot t}{sharpness}}}$$

Where t is exposure time, "R" denotes a rate for the whole bin in counts/s, and "P" denotes a
rate in counts/pixel/s.

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[9] https://www.stsci.edu/instruments/wfpc2/Wfpc2_hand2/ch6_exposuretime8.html

When -fastSNR is used, we compute the total signal and total noise by summing the signals and variances for the 2 pixels on either side of the spatial profile center, for each wavelength bin in the requested range wrange and for each slicer path (the spatial profile is assumed to be centered on a pixel boundary for symmetry and simplicity of coding). SNR is simply the ratio of these totals. This method does not have the optimal SNR but is available to help the user estimate SNR for analysis via "shortcut". A better method is to assume the observer will measure the signal by fitting a profile model to each wavelength bin. The profile shape is determined by a known, seeing-limited PSF projected onto the slicer sections, where the only free parameters are single amplitudes for each wavelength bin (3 slicer sections are fit simultaneously). In this case, the code calculates variances for those amplitudes using the covariance matrix of the pixels; this downweights pixels with relatively low individual signal-to-noise.
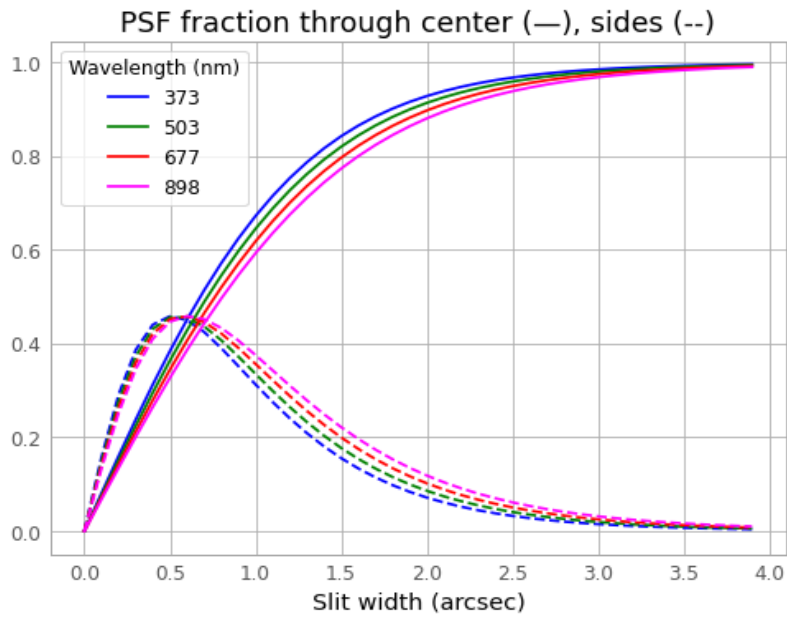
The SNR results are averaged over the wavelength bins within wrange. If the user is solving for exposure time, the SNR is calculated multiple times in a routine that searches for the exposure time that yields the requested SNR. In testing, the routine completes in under 10 iterations.

8   Useful Data

Table 1: Spectrograph channel parameters

Channel	λ (Å)	Å/pix	arcsec/pix
U	3100 – 4360	0.31	0.191
G	4170 – 5900	0.42	0.191
R	5610 – 7940	0.57	0.191
I	7560 – 10400	0.69	0.191

Figure 1: Slit efficiency

9   Acknowledgements