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# **platon Documentation**

***Release 4.0***

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**November 29, 2018: PLATON v3.0 is out! Please check the release notes on GitHub for the list of new features. Our paper actually describes v2.1, but v3 has a substantial number of improvements, and we strongly recommend everyone use it.**

**October 1, 2018: PLATON v2.0 is out! Please check the release notes for the list of new features, and upgrade.**



PLATON (PLANetary Atmospheric Transmission for Observer Noobs) is a fast and easy to use forward modelling and retrieval tool for exoplanet atmospheres. It is based on ExoTransmit by Eliza Kempton. The two main modules are:

1. *TransitDepthCalculator*: computes a transit spectrum for an exoplanet
2. *EclipseDepthCalculator*: computes an eclipse spectrum
3. *Retriever*: retrieves atmospheric properties of an exoplanet, given the observed transit spectrum. The properties that can be retrieved are metallicity, C/O ratio, cloudtop pressure, scattering strength, and scattering slope
4. *CombinedRetriever*: can retrieve atmospheric properties for eclipse depths, or a combination of transit and eclipse depths

The transit spectrum is calculated from 300 nm to 30  $\mu$ m, taking into account gas absorption, collisionally induced gas absorption, clouds, and scattering. *TransitDepthCalculator* is written entirely in Python and is designed for performance. By default, it calculates transit depths on a fine wavelength grid ( $\lambda/\Delta\lambda = 1000$  with 4616 wavelength points), which takes ~65 milliseconds on a midrange consumer computer. The user can instead specify bins which are directly relevant to matching observational data, in which case the code avoids computing depths for irrelevant wavelengths and is many times faster. The user can also download higher resolution data (R=2000 or R=10,000) from [here](#) and drop them into PLATON's data folder; the runtime is roughly proportional to the resolution.

The eclipse spectrum is calculated with the same physics included, but it does not include scattering as a source of emission; scattering is only included as a source of absorption.

The retrievers use *TransitDepthCalculator*/*EclipseDepthCalculator* as a forward model, and can retrieve atmospheric properties using either MCMC or nested sampling. Typically, nested sampling with only transit depths finishes in < 10 min. MCMC relies on the user to specify the number of iterations, but typically reaches convergence in less than an hour. Eclipse depths typically take longer to calculate by a factor of a few, resulting in longer retrievals.





## CHAPTER 2

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### Install

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Before installing PLATON, it is highly recommended to have a fast linear algebra library (BLAS) and verify that numpy is linked to it. This is because the heart of the radiative transfer code is a matrix multiplication operation conducted through `numpy.dot`, which in turn calls a BLAS library if it can find one. If it can't find one, your code will be many times slower.

On Linux, a good choice is OpenBLAS. You can install it on Ubuntu with:

```
sudo apt install libopenblas-dev
```

On OS X, a good choice is Accelerate/vecLib, which should already be installed by default.

To check if your numpy is linked to BLAS, do:

```
numpy.__config__.show()
```

If `blas_opt_info` mentions OpenBLAS or vecLib, that's a good sign. If it says "NOT AVAILABLE", that's a bad sign.

Once you have a BLAS installed and linked to numpy, download PLATON, install the requirements, and install PLATON itself. Although it is possible to install PLATON using pip (`pip install platon`), the recommended method is to clone the GitHub repository and install from there. This is because the repository includes examples, which you don't get when pip installing.

To install from GitHub:

```
git clone https://github.com/ideasrule/platon.git
cd platon/
python setup.py install
```

You can run unit tests to make sure everything works:

```
nosetests -v
```

The unit tests should also give you a good idea of how fast the code will be. On a decent Ubuntu machine with OpenBLAS, it takes 3 minutes.

The default data files (in `platon/data`) have a wavelength resolution of  $R=1000$ , but if you want higher resolution, you can download  $R=2000$  and  $R=10,000$  data from [this webpage](#)

If you have a CUDA-capable GPU and plan to use the eclipse depth calculator, you can take advantage of GPU acceleration. Install CUDA, cudamat, and gnumpy, in that order, and the eclipse depth calculator should automatically use find and use gnumpy.

## CHAPTER 3

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### Quick start

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The fastest way to get started is to look at the `examples/` directory, which has examples on how to compute transit/eclipse depths from planetary parameters, and on how to retrieve planetary parameters from transit/eclipse depths. This page is a short summary of the more detailed examples.

To compute transit depths, look at `transit_depth_example.py`, then go to [\*TransitDepthCalculator\*](#) for more info. In short:

```
from platon.transit_depth_calculator import TransitDepthCalculator
from platon.constants import M_jup, R_jup, R_sun

# All inputs and outputs for PLATON are in SI

Rs = 1.16 * R_sun
Mp = 0.73 * M_jup
Rp = 1.40 * R_jup
T = 1200

# The initializer loads all data files. Create a TransitDepthCalculator
# object and hold on to it
calculator = TransitDepthCalculator()

# compute_depths is fast once data files are loaded
wavelengths, depths, info_dict = calculator.compute_depths(Rs, Mp, Rp, T, logZ=0, CO_
↳ratio=0.53, full_output=True)
```

You can adjust a variety of parameters, including the metallicity ( $Z$ ) and C/O ratio. By default,  $\log Z = 0$  and  $C/O = 0.53$ . Any other value for  $\log Z$  and  $C/O$  in the range  $-1 < \log Z < 3$  and  $0.05 < C/O < 2$  can also be used. `full_output=True` indicates you'd like extra information about the atmosphere, which is returned in `info_dict`. `info_dict` includes parameters like the temperatures, pressures, radii, abundances, and molecular weights of each atmospheric layer, and the line of sight optical depth ( $\tau_{\text{los}}$ ) through each layer.

You can also specify custom abundances, such as by providing the filename of one of the abundance files included in the package (from `ExoTransmit`). The custom abundance files specified by the user must be compatible with the `ExoTransmit` format:

```
calculator.compute_depths(Rs, Mp, Rp, T, logZ=None, CO_ratio=None,
                          custom_abundances=filename)
```

To retrieve atmospheric parameters, look at `retrieve_example.py`, then go to [Retriever](#) for more info. In short:

```
from platon.fit_info import FitInfo
from platon.retriever import Retriever

# Set your best guess. T_star is used only to improve binning of transit
# depths.
fit_info = retriever.get_default_fit_info(Rs, Mp, Rp, T, logZ=0, T_star=6100)

# Decide what you want to fit for, and add those parameters to fit_info

# Fit for the stellar radius and planetary mass using Gaussian priors. This
# is a way to account for the uncertainties in the published values
fit_info.add_gaussian_fit_param('Rs', 0.02*R_sun)
fit_info.add_gaussian_fit_param('Mp', 0.04*M_jup)

# Fit for other parameters using uniform priors
fit_info.add_uniform_fit_param('R', 0.9*R_guess, 1.1*R_guess)
fit_info.add_uniform_fit_param('T', 0.5*T_guess, 1.5*T_guess)
fit_info.add_uniform_fit_param("log_scatt_factor", 0, 1)
fit_info.add_uniform_fit_param("logZ", -1, 3)
fit_info.add_uniform_fit_param("log_cloudtop_P", -0.99, 5)
fit_info.add_uniform_fit_param("error_multiple", 0.5, 5)

# Run nested sampling
result = retriever.run_multinest(bins, depths, errors, fit_info, plot_best=True)
```

Here, *bins* is a  $N \times 2$  array representing the start and end wavelengths of the bins, in metres; *depths* is a list of  $N$  transit depths; and *errors* is a list of  $N$  errors on those transit depths. *plot\_best=True* indicates that the best fit solution should be plotted, along with the measured transit depths and their errors.

The example above retrieves the planetary radius (at a reference pressure of 100,000 Pa), the temperature of the isothermal atmosphere, and the metallicity. Other parameters you can retrieve for are the stellar radius, the planetary mass, C/O ratio, the cloudtop pressure, the scattering factor, the scattering slope, and the error multiple—which multiplies all errors by a constant. We recommend either fixing the stellar radius and planetary mass to the measured values, or setting Gaussian priors on them to account for measurement errors.

Once you get the *result* object, you can make a corner plot:

```
fig = corner.corner(result.samples, weights=result.weights,
                    range=[0.99] * result.samples.shape[1],
                    labels=fit_info.fit_param_names)
```

Additionally, *result.logl* stores the log likelihoods of the points in *result.samples*.

If you prefer using MCMC instead of Nested Sampling in your retrieval, you can use the *run\_emcee* method instead of the *run\_multinest* method. Do note that Nested Sampling tends to be much faster and it does not require specification of a termination point:

```
result = retriever.run_emcee(bins, depths, errors, fit_info)
```

For MCMC, the number of walkers and iterations/steps can also be specified. The *result* object returned by *run\_emcee* is different from that returned by *run\_multinest*. To make a corner plot with the result of *run\_emcee*:

```
fig = corner.corner(result.flatchain, range=[0.99] * result.flatchain.shape[1],
                    labels=fit_info.fit_param_names)
```



## CHAPTER 4

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### Mie scattering

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By default, PLATON uses a parametric model to account for scattering, with an amplitude and a slope. However, PLATON also has the ability to compute Mie scattering in place of the parametric model.

To use Mie scattering, follow [Quick start](#) to see how to do forward models and retrievals using the default parametric model. To use Mie scattering instead:

```
calculator.compute_depths(Rs, Mp, Rp, T,
    ri = 1.33-0.1j, frac_scale_height = 0.5, number_density = 1e9,
    part_size = 1e-6, cloudtop_pressure=1e5)
```

This computes Mie scattering for particles with complex refractive index  $1.33-0.1j$ . The particles follow a lognormal size distribution with a mean radius of 1 micron and standard deviation of 0.5. They have a density of  $10^9/m^3$  at the cloud-top pressure of  $10^5$  Pa, declining with altitude with a scale height of 0.5 times the gas scale height.

To retrieve Mie scattering parameters, make sure to set `log_scatt_factor` to `-np.inf`, `log_number_density` to a finite value, and `ri` to the complex refractive index of the scattering particles (which cannot be a free parameter):

```
fit_info = retriever.get_default_fit_info(Rs, Mp, Rp, T,
    log_scatt_factor = -np.inf, log_number_density = 9, ri = 1.33-0.1j)

fit_info.add_uniform_fit_param('log_number_density', 5, 15)
fit_info.add_uniform_fit_param('log_part_size', -7, -4)
```





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## Eclipse depths

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Although PLATON began life as a transmission spectrum calculator, we have also written an eclipse depth calculator and retriever.

To use the eclipse depth calculator, first create a temperature-pressure profile:

```
from platon.TP_profile import Profile
p = Profile()
p.set_parametric(1200, 500, 0.5, 0.6, 1e6, 1900)
```

This creates a parametric T-P profile according to [Madhusudhan & Seager 2009](#). The parameters are:  $T_0$ ,  $P_1$ ,  $\alpha_1$ ,  $\alpha_2$ ,  $P_3$ ,  $T_3$ .  $P_0$  is set to  $10^{-4}$  Pa, while  $P_2$  and  $T_2$  are derived from the six specified parameters.

Then, call the eclipse depth calculator:

```
from eclipse_depth_calculator import EclipseDepthCalculator

wavelengths, depths = calc.compute_depths(p, Rs, Mp, Rp, Tstar)
```

Most of the same parameters accepted by the transit depth calculator are also accepted by the eclipse depth calculator.

It is also possible to retrieve on combined transit and eclipse depths:

```
from platon.combined_retriever import CombinedRetriever

retriever = CombinedRetriever()
fit_info = retriever.get_default_fit_info(Rs, Mp, Rp, T_limb,
                                          T0=1200, P1=500, alpha1=0.5, alpha2=0.6, P3=1e6, T3=1900)

fit_info.add_uniform_fit_param(...)
fit_info.add_uniform_fit_param(...)

result = retriever.run_multinest(transit_bins, transit_depths, transit_errors,
                                eclipse_bins, eclipse_depths, eclipse_errors,
                                fit_info)
```

Here,  $T_{\text{limb}}$  is the temperature at the planetary limb (used for transit depths), while the T-P profile parameters are for the dayside (used for eclipse depths).

## CHAPTER 6

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### Visualizer

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If you want to see what your exoplanet might look like in transit, the Visualizer module is for you! Visualizer uses the absorption profile calculated by the transit depth calculator, which you can get using:

```
calculator = TransitDepthCalculator()
wavelengths, depths, info = calculator.compute_depths(Rs, Mp, Rp, T, full_output=True)
```

Then, to draw an image:

```
color_bins = 1e-6 * np.array([
    [4, 5],
    [3.2, 4],
    [1.1, 1.7]])
visualizer = Visualizer()
image, m_per_pix = visualizer.draw(info, color_bins, method='disk')
```

This maps all wavelengths between 4–5 microns to red, while 3.2–4 microns maps to green and 4–5 microns maps to blue. The draw function returns an image and an image scale, in meters per pixel. The image can be displayed with pyplot:

```
plt.imshow(image)
```

The ‘method’ argument can either be ‘disk’ or ‘layers’. The difference is illustrated in the example images below. For purely aesthetic purposes, we have also made the star light a pale yellow color by passing [1,1,0.8] to the star\_color argument of draw.



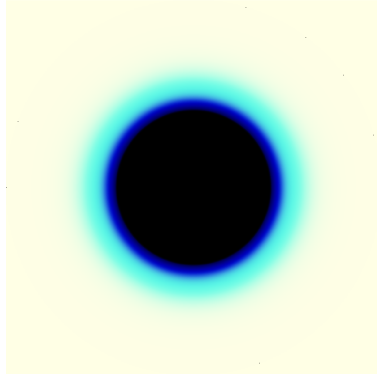


Fig. 2: 55 Cnc e as a disk transiting a yellow star

## Questions & Answers

This document describes niche use cases that the Quick Start does not cover. For typical usage patterns, consult the files in examples/ and the Quick Start, in that order.

- **What physics does PLATON take into account?**

We account for gas absorption, collisional absorption, an opaque cloud deck, and scattering with user-specified slope and amplitude (or Rayleigh, if not specified). 34 chemical species are included in our calculations, namely the ones listed in data/species\_info. The abundances of these species were calculated using GGchem for a grid of metallicity, C/O ratio, temperature, and pressure, assuming equilibrium chemistry. Metallicity ranges from 0.1-1000x solar, C/O ratio from 0.05 to 2, temperature from 300 to 3000 K, and pressure from  $10^{-4}$  to  $10^8$  Pa. If you wander outside these limits, PLATON will throw a ValueError.

- **Why does PLATON not exactly agree with ExoTransmit?**

We have made many improvements to the ExoTransmit algorithm to enhance the accuracy of our transit depth calculations. Among the most consequential are allowing the gravitational acceleration to vary with height, and truncating the atmosphere at  $10^{-4}$  Pa instead of 0.1 Pa. Both of these changes tend to increase the transit depth. Precise agreement with ExoTransmit should not be expected.

- **How do I use PLATON with ExoTransmit input files? Or: how do I specify custom abundances and T/P profiles?**

By example:

```
from platon.abundance_getter import AbundanceGetter
from platon.transit_depth_calculator import TransitDepthCalculator

_, pressures, temperatures = np.loadtxt("t_p_1200K.dat", skiprows=1, unpack=True)

# These files are found in examples/custom_abundances. They are equivalent
# to the ExoTransmit EOS files, except that COS is renamed to OCS
abundances = AbundanceGetter.from_file("abund_1Xsolar_cond.dat")

calculator = TransitDepthCalculator()
wavelengths, transit_depths = calculator.compute_depths(star_radius, planet_mass,
↳ planet_radius, temperature=None, logZ=None, CO_ratio=None, custom_
↳ abundances=abundances, custom_T_profile=temperatures, custom_P_ (continues on next page)
↳ profile=pressures)
```

- **Should I use PLATON with ExoTransmit input files?**

No. The recommended usage is much simpler, and is outlined in both the examples/ directory and the Quick Start.

- **Which parameters are supported in retrieval?** See the documentation for `get_default_fit_info()`. All arguments to this method are possible fit parameters. However, we recommend not fitting for  $T_{\text{star}}$ , as it has a very small effect on the result to begin with.  $M_p$  and  $R_s$  are usually measured to greater precision than you can achieve in a fit, but we recommend fitting them with Gaussian priors to take into account the measurement errors.

- **Should I use `run_multinest`, or `run_emcee`?**

That depends on whether you like nested sampling or MCMC! You should try both and compare the results. Nested sampling is usually faster and has an automatically determined stopping point, so we recommend starting with that. However, we have encountered cases where nested sampling stalls and does not finish even after many weeks. In such cases, use MCMC.

- **My corner plots look ugly. What do I do?**

If you're using nested sampling, increase the number of live points. This will increase the number of samples your corner plot is generated from:

```
# By default, npoints is 100
result = retriever.run_multinest(bins, depths, errors, fit_info, npoints=1000)
```

If you're using MCMC, increase `nsteps` from the default of 1000 to 10,000.

- **How do I get statistics from the retrieval?**

Look at `BestFit.txt`. It'll have the 16th, 50th, and 84th percentiles of all parameters, as well as the best fit values.

- **How do I do check what effect a species has on the transit spectrum?** You can tweak the atmospheric abundances and see what happens. First, get baseline abundances:

```
from platon.abundance_getter import AbundanceGetter
getter = AbundanceGetter()
# Solar logZ and C/O ratio. Modify as required.
abundances = getter.get(0, 0.53)
```

You can then modify this at will:

```
# Zero out CO. (Note that if CO is a major component, you should probably
# renormalize the abundances of other species so that they add up to 1.)

abundances["CO"] *= 0

# Set CH4 abundance to a constant throughout the atmosphere
abundances["CH4"] *= 0
abundances["CH4"] += 1e-5
```

Then call `compute_depths` with `logZ` and `CO_ratio` set to `None`:

```
calculator.compute_depths(star_radius, planet_mass, planet_radius, temperature,
    ↳ logZ=None, CO_ratio=None, custom_abundances=abundances)
```

- **How do I specify custom abundances in the forward model?** See the answer to the above question. If you want to specify different abundances for each temperature/pressure point instead of a constant abundance, see the documentation for custom\_abundances in `compute_depths()`
- **How do I retrieve individual species abundances?** You can't. While this would be trivial to implement—and you can do so if you really need to—it could easily lead to combinations of species that are unstable on very short timescales. We have therefore decided not to support retrieving on individual abundances.
- **PLATON is still too slow! How do I make it faster?**

If you didn't follow the installation instructions, go back and re-read them. Make sure you have OpenBLAS, MKL, or another basic linear algebra library (BLAS) installed and linked to numpy. If you intend to use the eclipse depth calculator and have a CUDA-capable GPU, install CUDA, cudamat, and gnumpy; the eclipse depth calculator should detect gnumpy and use the GPU.

If PLATON is still too slow, try decreasing `num_profile_heights` in `transit_depth_calculator.py` (for transit depths) or `TP_profile` (for eclipse depths). Of course, this comes at the expense of accuracy. You can also delete some of the files in `data/Absorption` that correspond to molecules which contribute negligible opacity. This has the effect of setting their absorption cross section to 0.

We have experienced cases where the nested sampling retrieval seemingly gets stuck, and doesn't finish even after many weeks. In these cases, try MCMC instead, as that is guaranteed to terminate in the number of steps you specify.





## 8.1 platon package

### 8.1.1 Submodules

### 8.1.2 platon.TP\_profile module

```
class platon.TP_profile.Profile (num_profile_heights=250)
    Bases: object

    set_from_arrays (P_profile, T_profile)

    set_from_opacity (T_irr, info_dict, visible_cutoff=8e-07, T_int=100)

    set_from_params_dict (profile_type, params_dict)

    set_from_radiative_solution (T_star, Rs, a, Mp, Rp, beta, log_k_th, log_gamma,
                                log_gamma2=None, alpha=0, T_int=100, **ignored_kwargs)
        From Line et al. 2013: http://adsabs.harvard.edu/abs/2013ApJ...775..137L, Equation 13 - 16

    set_isothermal (T_day)

    set_parametric (T0, P1, alpha1, alpha2, P3, T3)
        Parametric model from https://arxiv.org/pdf/0910.1347.pdf
```

### 8.1.3 platon.abundance\_getter module

```
class platon.abundance_getter.AbundanceGetter (include_condensation=True)
    Bases: object

    static from_file (filename)
        Reads abundances file in the ExoTransmit format (called “EOS” files in ExoTransmit), returning a dictionary mapping species name to an abundance array of dimension
```

**get** (*logZ*, *CO\_ratio*=0.53)

Get an abundance grid at the specified logZ and C/O ratio. This abundance grid can be passed to Transit-DepthCalculator, with or without modifications. The end user should not need to call this except in rare cases.

**Returns abundances** – A dictionary mapping species name to a 2D abundance array, specifying the number fraction of the species at a certain temperature and pressure.

**Return type** dict of np.ndarray

**is\_in\_bounds** (*logZ*, *CO\_ratio*, *T*)

Check to see if a certain metallicity, C/O ratio, and temperature combination is within the supported bounds

### 8.1.4 platon.combined\_retriever module

**class** platon.combined\_retriever.CombinedRetriever

Bases: object

**static get\_default\_fit\_info** (*Rs*, *Mp*, *Rp*, *T*=None, *logZ*=0, *CO\_ratio*=0.53, *log\_cloudtop\_P*=inf, *log\_scatt\_factor*=0, *scatt\_slope*=4, *error\_multiple*=1, *T\_star*=None, *T\_spot*=None, *spot\_cov\_frac*=None, *frac\_scale\_height*=1, *log\_number\_density*=-inf, *log\_part\_size*=-6, *ri*=None, *profile\_type*='isothermal', *\*\*profile\_kwargs*)

Get a *FitInfo* object filled with best guess values. A few parameters are required, but others can be set to default values if you do not want to specify them. All parameters are in SI.

#### Parameters

- **Rs** (*float*) – Stellar radius
- **Mp** (*float*) – Planetary mass
- **Rp** (*float*) – Planetary radius
- **T** (*float*) – Temperature of the isothermal planetary atmosphere
- **logZ** (*float*) – Base-10 logarithm of the metallicity, in solar units
- **CO\_ratio** (*float, optional*) – C/O atomic ratio in the atmosphere. The solar value is 0.53.
- **log\_cloudtop\_P** (*float, optional*) – Base-10 log of the pressure level (in Pa) below which light cannot penetrate. Use np.inf for a cloudless atmosphere.
- **log\_scatt\_factor** (*float, optional*) – Base-10 logarithm of scattering factoring, which make scattering that many times as strong. If *scatt\_slope* is 4, corresponding to Rayleigh scattering, the absorption coefficients are simply multiplied by *scattering\_factor*. If slope is not 4, *scattering\_factor* is defined such that the absorption coefficient is that many times as strong as Rayleigh scattering at the reference wavelength of 1 um.
- **scatt\_slope** (*float, optional*) – Wavelength dependence of scattering, with 4 being Rayleigh.
- **error\_multiple** (*float, optional*) – All error bars are multiplied by this factor.
- **T\_star** (*float, optional*) – Effective temperature of the star. This is used to make wavelength binning of transit depths more accurate.
- **T\_spot** (*float, optional*) – Effective temperature of the star spots. This is used to make wavelength dependent correction to the observed transit depths.

- **spot\_cov\_frac** (*float, optional*) – The spot covering fraction of the star by area. This is used to make wavelength dependent correction to the transit depths.

**Returns** **fit\_info** – This object is used to indicate which parameters to fit for, which to fix, and what values all parameters should take.

**Return type** *FitInfo* object

**pretty\_print** (*fit\_info*)

**run\_emcee** (*transit\_bins, transit\_depths, transit\_errors, eclipse\_bins, eclipse\_depths, eclipse\_errors, fit\_info, nwalkers=50, nsteps=1000, include\_condensation=True, plot\_best=False*)

Runs affine-invariant MCMC to retrieve atmospheric parameters.

#### Parameters

- **transit\_bins** (*array\_like, shape (N,2)*) – Wavelength bins, where `wavelength_bins[i][0]` is the start wavelength and `wavelength_bins[i][1]` is the end wavelength for bin *i*.
- **transit\_depths** (*array\_like, length N*) – Measured transit depths for the specified wavelength bins
- **transit\_errors** (*array\_like, length N*) – Errors on the aforementioned transit depths
- **eclipse\_bins** (*array\_like, shape (N,2)*) – Wavelength bins, where `wavelength_bins[i][0]` is the start wavelength and `wavelength_bins[i][1]` is the end wavelength for bin *i*.
- **eclipse\_depths** (*array\_like, length N*) – Measured eclipse depths for the specified wavelength bins
- **eclipse\_errors** (*array\_like, length N*) – Errors on the aforementioned eclipse depths
- **fit\_info** (*FitInfo* object) – Tells the method what parameters to freely vary, and in what range those parameters can vary. Also sets default values for the fixed parameters.
- **nwalkers** (*int, optional*) – Number of walkers to use
- **nsteps** (*int, optional*) – Number of steps that the walkers should walk for
- **include\_condensation** (*bool, optional*) – When determining atmospheric abundances, whether to include condensation.
- **plot\_best** (*bool, optional*) – If True, plots the best fit model with the data

**Returns** **result** – This returns emcee’s EnsembleSampler object. The most useful attributes in this item are `result.chain`, which is a (W x S x P) array where W is the number of walkers, S is the number of steps, and P is the number of parameters; and `result.Inprobability`, a (W x S) array of log probabilities. For your convenience, this object also contains `result.flatchain`, which is a (WS x P) array where WS = W x S is the number of samples; and `result.flatlnprobability`, an array of length WS

**Return type** EnsembleSampler object

**run\_multinest** (*transit\_bins, transit\_depths, transit\_errors, eclipse\_bins, eclipse\_depths, eclipse\_errors, fit\_info, include\_condensation=True, plot\_best=False, max\_iter=None, maxcall=None, nlive=100, \*\*dynesty\_kwargs*)

Runs nested sampling to retrieve atmospheric parameters.

#### Parameters

- **transit\_bins** (*array\_like, shape (N,2)*) – Wavelength bins, where `wavelength_bins[i][0]` is the start wavelength and `wavelength_bins[i][1]` is the end wavelength for bin *i*.
- **transit\_depths** (*array\_like, length N*) – Measured transit depths for the specified wavelength bins

- **transit\_errors** (*array\_like, length N*) – Errors on the aforementioned transit depths
- **eclipse\_bins** (*array\_like, shape (N,2)*) – Wavelength bins, where `wavelength_bins[i][0]` is the start wavelength and `wavelength_bins[i][1]` is the end wavelength for bin *i*.
- **eclipse\_depths** (*array\_like, length N*) – Measured eclipse depths for the specified wavelength bins
- **eclipse\_errors** (*array\_like, length N*) – Errors on the aforementioned eclipse depths
- **fit\_info** (*FitInfo* object) – Tells us what parameters to freely vary, and in what range those parameters can vary. Also sets default values for the fixed parameters.
- **include\_condensation** (*bool, optional*) – When determining atmospheric abundances, whether to include condensation.
- **plot\_best** (*bool, optional*) – If True, plots the best fit model with the data
- **nlive** (*int*) – Number of live points to use for nested sampling
- **\*\*dynesty\_kwargs** (*keyword arguments to pass to dynesty's NestedSampler*)

**Returns result** – This returns dynesty’s NestedSampler ‘results’ field, slightly modified. The object is dictionary-like and has many useful items. For example, `result.samples` (or alternatively, `result[“samples”]`) are the parameter values of each sample, `result.logwt` contains the  $\log(\text{weights})$ , `result.weights` contains the normalized weights (this is added by PLATON), `result.logl` contains the  $\ln$  likelihoods, and `result.logp` contains the  $\ln$  posteriors (this is added by PLATON). `result.logz` is the natural logarithm of the evidence.

**Return type** Result object

### 8.1.5 platon.constants module

```
platon.constants.AU = 149597870700.0
    Astronomical unit

platon.constants.M_earth = 5.97236e+24
    Earth mass

platon.constants.M_jup = 1.89819e+27
    Jupiter mass

platon.constants.M_sun = 1.98848e+30
    Solar mass

platon.constants.R_earth = 6378100.0
    Earth radius

platon.constants.R_jup = 71492000.0
    Jupiter radius

platon.constants.R_sun = 695700000.0
    Solar radius
```

### 8.1.6 platon.eclipse\_depth\_calculator module

```
class platon.eclipse_depth_calculator.EclipseDepthCalculator
    Bases: object

    change_wavelength_bins (bins)
        Same functionality as change_wavelength_bins()
```

```
compute_depths (t_p_profile, star_radius, planet_mass, planet_radius, T_star, logZ=0,
                  CO_ratio=0.53, add_gas_absorption=True, add_scattering=True, scat-
                  tering_factor=1, scattering_slope=4, scattering_ref_wavelength=1e-
                  06, add_collisional_absorption=True, cloudtop_pressure=inf, cus-
                  tom_abundances=None, T_spot=None, spot_cov_frac=None, ri=None,
                  frac_scale_height=1, number_density=0, part_size=1e-06, full_output=False)
```

Most parameters are explained in [compute\\_depths\(\)](#)

**Parameters** *t\_p\_profile* (*Profile*) – A Profile object from TP\_profile

## 8.1.7 platon.errors module

**exception** `platon.errors.AtmosphereError`

Bases: `Exception`

## 8.1.8 platon.fit\_info module

**class** `platon.fit_info.FitInfo` (*guesses\_dict*)

Bases: `object`

**add\_gaussian\_fit\_param** (*name*, *std*, *low\_guess*=None, *high\_guess*=None)

Fit for the parameter *name* using a Gaussian prior with standard deviation *std*. If using emcee, the walkers' initial values for this parameter are randomly selected to be between *low\_guess* and *high\_guess*. If *low\_guess* is None, it is set to mean-2\*std; if *high\_guess* is None, it is set to mean+2\*std.

**add\_uniform\_fit\_param** (*name*, *low\_lim*, *high\_lim*, *low\_guess*=None, *high\_guess*=None)

Fit for the parameter *name* using a uniform prior between *low\_lim* and *high\_lim*. If using emcee, the walkers' initial values for this parameter are randomly selected to be between *low\_guess* and *high\_guess*. If not specified, *low\_guess* is set to *low\_lim*, and similarly with *high\_guess*.

## 8.1.9 platon.retriever module

**class** `platon.retriever.Retriever`

Bases: `object`

**static get\_default\_fit\_info** (*Rs*, *Mp*, *Rp*, *T*, *logZ*=0, *CO\_ratio*=0.53, *log\_cloudtop\_P*=inf,
 *log\_scatt\_factor*=0, *scatt\_slope*=4, *error\_multiple*=1,
 *T\_star*=None, *T\_spot*=None, *spot\_cov\_frac*=None,
 *frac\_scale\_height*=1, *log\_number\_density*=-inf,
 *log\_part\_size*=-6, *part\_size\_std*=0.5, *ri*=None)

Get a [FitInfo](#) object filled with best guess values. A few parameters are required, but others can be set to default values if you do not want to specify them. All parameters are in SI. For information on the parameters, see the documentation for [compute\\_depths\(\)](#)

**Returns** *fit\_info* – This object is used to indicate which parameters to fit for, which to fix, and what values all parameters should take.

**Return type** [FitInfo](#) object

**run\_emcee** (*wavelength\_bins*, *depths*, *errors*, *fit\_info*, *nwalkers*=50, *nsteps*=1000, *in*-  
*clude\_condensation*=True, *plot\_best*=False)

Runs affine-invariant MCMC to retrieve atmospheric parameters.

**Parameters**

- **wavelength\_bins** (*array\_like, shape (N,2)*) – Wavelength bins, where wavelength\_bins[i][0] is the start wavelength and wavelength\_bins[i][1] is the end wavelength for bin i.
- **depths** (*array\_like, length N*) – Measured transit depths for the specified wavelength bins
- **errors** (*array\_like, length N*) – Errors on the aforementioned transit depths
- **fit\_info** (*FitInfo* object) – Tells the method what parameters to freely vary, and in what range those parameters can vary. Also sets default values for the fixed parameters.
- **nwalkers** (*int, optional*) – Number of walkers to use
- **nsteps** (*int, optional*) – Number of steps that the walkers should walk for
- **include\_condensation** (*bool, optional*) – When determining atmospheric abundances, whether to include condensation.
- **plot\_best** (*bool, optional*) – If True, plots the best fit model with the data

**Returns result** – This returns emcee’s EnsembleSampler object. The most useful attributes in this item are result.chain, which is a (W x S x P) array where W is the number of walkers, S is the number of steps, and P is the number of parameters; and result.lnprobability, a (W x S) array of log probabilities. For your convenience, this object also contains result.flatchain, which is a (WS x P) array where WS = W x S is the number of samples; and result.flatlnprobability, an array of length WS

**Return type** EnsembleSampler object

**run\_multinest** (*wavelength\_bins, depths, errors, fit\_info, include\_condensation=True, plot\_best=False, maxiter=None, maxcall=None, nlive=100, \*\*dynesty\_kwargs*)

Runs nested sampling to retrieve atmospheric parameters.

#### Parameters

- **wavelength\_bins** (*array\_like, shape (N,2)*) – Wavelength bins, where wavelength\_bins[i][0] is the start wavelength and wavelength\_bins[i][1] is the end wavelength for bin i.
- **depths** (*array\_like, length N*) – Measured transit depths for the specified wavelength bins
- **errors** (*array\_like, length N*) – Errors on the aforementioned transit depths
- **fit\_info** (*FitInfo* object) – Tells us what parameters to freely vary, and in what range those parameters can vary. Also sets default values for the fixed parameters.
- **include\_condensation** (*bool, optional*) – When determining atmospheric abundances, whether to include condensation.
- **plot\_best** (*bool, optional*) – If True, plots the best fit model with the data
- **nlive** (*int*) – Number of live points to use for nested sampling
- **\*\*dynesty\_kwargs** (*keyword arguments to pass to dynesty’s NestedSampler*)

**Returns result** – This returns ‘results’ of the NestedSampler object. It is dictionary-like and has many useful items. For example, result.samples (or alternatively, result[“samples”]) are the parameter values of each sample, result.weights contains the weights, and result.logl contains the log likelihoods. result.logz is the natural logarithm of the evidence.

**Return type** Result object

### 8.1.10 platon.transit\_depth\_calculator module

**class** `platon.transit_depth_calculator.TransitDepthCalculator` (*include\_condensation=True, num\_profile\_heights=250, ref\_pressure=100000.0*)

Bases: `object`

**\_\_init\_\_** (*include\_condensation=True, num\_profile\_heights=250, ref\_pressure=100000.0*)  
All physical parameters are in SI.

#### Parameters

- **include\_condensation** (*bool*) – Whether to use equilibrium abundances that take condensation into account.
- **num\_profile\_heights** (*int*) – The number of zones the atmosphere is divided into
- **ref\_pressure** (*float*) – The planetary radius is defined as the radius at this pressure

**change\_wavelength\_bins** (*bins*)

Specify wavelength bins, instead of using the full wavelength grid in `self.lambda_grid`. This makes the code much faster, as `compute_depths` will only compute depths at wavelengths that fall within a bin.

**Parameters** *bins* (*array\_like, shape (N,2)*) – Wavelength bins, where `bins[i][0]` is the start wavelength and `bins[i][1]` is the end wavelength for bin *i*. If *bins* is `None`, resets the calculator to its unbinned state.

**Raises** `NotImplementedError` – Raised when `change_wavelength_bins` is called more than once, which is not supported.

**compute\_depths** (*star\_radius, planet\_mass, planet\_radius, temperature, logZ=0, CO\_ratio=0.53, add\_gas\_absorption=True, add\_scattering=True, scattering\_factor=1, scattering\_slope=4, scattering\_ref\_wavelength=1e-06, add\_collisional\_absorption=True, cloudtop\_pressure=inf, custom\_abundances=None, custom\_T\_profile=None, custom\_P\_profile=None, T\_star=None, T\_spot=None, spot\_cov\_frac=None, ri=None, frac\_scale\_height=1, number\_density=0, part\_size=1e-06, part\_size\_std=0.5, full\_output=False, min\_abundance=1e-99*)

Computes transit depths at a range of wavelengths, assuming an isothermal atmosphere. To choose bins, call `change_wavelength_bins()`.

#### Parameters

- **star\_radius** (*float*) – Radius of the star
- **planet\_mass** (*float*) – Mass of the planet, in kg
- **planet\_radius** (*float*) – Radius of the planet at 100,000 Pa. Must be in metres.
- **temperature** (*float*) – Temperature of the isothermal atmosphere, in Kelvin
- **logZ** (*float*) – Base-10 logarithm of the metallicity, in solar units
- **CO\_ratio** (*float, optional*) – C/O atomic ratio in the atmosphere. The solar value is 0.53.
- **add\_gas\_absorption** (*float, optional*) – Whether gas absorption is accounted for
- **add\_scattering** (*bool, optional*) – whether Rayleigh scattering is taken into account
- **scattering\_factor** (*float, optional*) – if `add_scattering` is `True`, make scattering this many times as strong. If `scattering_slope` is 4, corresponding to Rayleigh scattering, the absorption coefficients are simply multiplied by `scattering_factor`. If slope is not 4, `scattering_factor` is defined such that the absorption coefficient is that many times as strong as Rayleigh scattering at `scattering_ref_wavelength`.

- **scattering\_slope** (*float, optional*) – Wavelength dependence of scattering, with 4 being Rayleigh.
- **scattering\_ref\_wavelength** (*float, optional*) – Scattering is *scattering\_factor* as strong as Rayleigh at this wavelength, expressed in metres.
- **add\_collisional\_absorption** (*float, optional*) – Whether collisionally induced absorption is taken into account
- **cloudtop\_pressure** (*float, optional*) – Pressure level (in Pa) below which light cannot penetrate. Use `np.inf` for a cloudless atmosphere.
- **custom\_abundances** (*str or dict of np.ndarray, optional*) – If specified, overrides *logZ* and *CO\_ratio*. Can specify a filename, in which case the abundances are read from a file in the format of the EOS/ files. These are identical to ExoTransmit’s EOS files. It is also possible, though highly discouraged, to specify a dictionary mapping species names to numpy arrays, so that `custom_abundances['Na']` would mean the fractional number abundance of Na at a temperature of `self.T_grid[3]` and pressure of `self.P_grid[4]`.
- **custom\_T\_profile** (*array-like, optional*) – If specified and *custom\_P\_profile* is also specified, divides the atmosphere into user-specified P/T points, instead of assuming an isothermal atmosphere with *T = temperature*.
- **custom\_P\_profile** (*array-like, optional*) – Must be specified along with *custom\_T\_profile* to use a custom P/T profile. Pressures must be in Pa.
- **T\_star** (*float, optional*) – Effective temperature of the star. If you specify this and use wavelength binning, the wavelength binning becomes more accurate.
- **T\_spot** (*float, optional*) – Effective temperature of the star spots. This can be used to make wavelength dependent correction to the observed transit depths.
- **spot\_cov\_frac** (*float, optional*) – The spot covering fraction of the star by area. This can be used to make wavelength dependent correction to the transit depths.
- **ri** (*complex, optional*) – Complex refractive index  $n - ik$  (where  $k > 0$ ) of the particles responsible for Mie scattering. If provided, Mie scattering will be computed. In that case, *scattering\_factor* and *scattering\_slope* must be set to 1 and 4 (the default values) respectively.
- **frac\_scale\_height** (*float, optional*) – The number density of Mie scattering particles is proportional to  $P^{(1/frac\_scale\_height)}$ . This is similar to, but a bit different from, saying that the scale height of the particles is *frac\_scale\_height* times that of the gas.
- **number\_density** (*float, optional*) – The number density (in  $m^{-3}$ ) of Mie scattering particles
- **part\_size** (*float, optional*) – The mean radius of Mie scattering particles. The distribution is assumed to be log-normal, with a standard deviation of *part\_size\_std*
- **part\_size\_std** (*float, optional*) – The geometric standard deviation of particle radii. We recommend leaving this at the default value of 0.5.
- **full\_output** (*bool, optional*) – If True, returns *info\_dict* as a third return value.

**Raises** `ValueError` – Raised when invalid parameters are passed to the method

#### Returns

- **wavelengths** (*array of float*) – Central wavelengths, in metres
- **transit\_depths** (*array of float*) – Transit depths at *wavelengths*



- **info\_dict** (*dict*) – Returned if `full_output` is `True`, containing intermediate quantities calculated by the method. These are: `absorption_coeff_atm`, `tau_los`, `stellar_spectrum`, `radii`, `P_profile`, `T_profile`, `mu_profile`, `atm_abundances`, `unbinned_depths`, `unbinned_wavelengths`

### 8.1.11 platon.visualizer module

**class** `platon.visualizer.Visualizer` (*size=1000*)

Bases: `object`

**draw** (*transit\_info*, *color\_bins*, *star\_color=[1, 1, 1]*, *method='disk'*, *star\_radius=None*, *star\_margin=0.5*, *max\_dist=None*, *blur\_std=1*)  
 Draws an image of a transiting exoplanet.

#### Parameters

- **transit\_info** (*dict*) – the dictionary returned by `compute_depths` in `TransitDepthCalculator` when `full_output = True`
- **color\_bins** (*array-like, shape (3,2)*) – Wavelength bins to use for the R, G, B channels. For example, if `color_bins[0]` is `[3e-6, 4e-6]`, the red channel will reflect all light transmitted through the atmosphere between 3 and 4 microns.
- **star\_color** (*array-like, length 3, optional*) – R, G, B values of the star light, with `[1,1,1]` being white
- **method** (*str, optional*) – Either `'disk'` to draw the entire planetary disk with atmosphere, or `'layers'` to draw a 1D atmospheric profile—essentially an extreme zoom-in on the disk.
- **star\_radius** (*float, optional*) – Stellar radius, in meters. If given, the stellar limb will be drawn
- **star\_margin** (*float, optional*) – Distance from left side of canvas to stellar limb is `star_margin * max_dist`
- **max\_dist** (*float, optional*) – Maximum distance from planet center to draw, in meters
- **blur\_std** (*float, optional*) – STD of Gaussian blur to apply, in pixels

**Returns** `canvas` – The image of the planet. Can be displayed with `plt.imshow()`

**Return type** `array, shape (self.size, self.size, 3)`

### 8.1.12 Module contents



## CHAPTER 9

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