
Lenstool

Release 8.1

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Lenstool is a gravitational lensing software for modelling mass distribution of galaxies and clusters (strong and weak regime).

Further information may be found in the [Lenstool WikiStart](#).

Note: For the moment, this tutorial is only focusing on the introduction of idPIE potentials to perform the joint X-ray and lensing optimisation model of the density of dark matter and intra-cluster medium.

Check out the [idPIE profile description](#) section for further information on idPIE profiles, and [Tutorial](#) for a short tutorial on their usage in `lenstool`.

Note: This project is under active development. It is compatible with v8 of `lenstool`.

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1.1 Installation

1.1.1 GitHub installation

To use the modified version of `lenstool`, first `git clone` it:

```
git clone https://github.com/njzifjoiez/Lenstool_Bspline
```

and switch branch:

```
git checkout idPIE-pot-joint
```

Note: TODO: HERE detail the installation if necessary

1.2 idPIE profile description

1.2.1 dPIE summary

A summary on the **dual Pseudo-Isothermal Elliptical** matter distribution (dPIE) may be found [here](#), and this type of gravitational potential is described at length in [Eliasdóttir et al. \(2007, Appendix A\)](#). It is identified in `lenstool` by id: 81.

Assuming we neglect ellipticity in this documentation, dPIE profiles write:

$$\rho_{\text{dPIE}}(r) = \frac{\rho_0}{\left[1 + \left(\frac{r}{s}\right)^2\right] \left[1 + \left(\frac{r}{a}\right)^2\right]}$$

where ρ_0 is the density normalisation, a the core radius, and s the cut radius.

A sum of dPIE profiles may be assumed to represent the total matter density ρ_m (baryons + dark matter) in the lens:

$$\rho_m = \sum_i \rho_{\text{dPIE},i}.$$

Thus the profile of the gravitational potential Φ may be deduced from the dPIE sum:

$$\Phi(r) = -4\pi G \sum_i \int_0^r ds s^{-2} \int_0^s dt t^2 \rho_{\text{dPIE},i}(t).$$

For one dPIE profile $\rho_{\text{dPIE}}(r)$, the potential writes:

$$\Phi_{\text{dPIE}}(r) = \frac{a^2 s^2}{a^2 - s^2} \left[\frac{s}{r} \arctan \frac{r}{s} - \frac{a}{r} \arctan \frac{r}{a} + \frac{1}{2} \ln \left(\frac{r^2 + s^2}{r^2 + a^2} \right) \right].$$

1.2.2 Hydrostatic idPIE n_e ICM density profile

If we assume the intra-cluster medium (ICM) to be in hydrostatic equilibrium, we may simplify the Navier-Stokes equation to:

$$\frac{\partial_r (n_e T_e)}{n_e} = \frac{\mu_g m_a}{k_B} \partial_r \Phi,$$

where n_e is the ICM electron number volume density, T_e the ICM electron temperature, $\mu_g \approx 0.60$ the mean molecular weight of the ICM gas, $m_a \approx 1.66 \times 10^{-27}$ kg the unified atomic mass, and k_B the Boltzmann constant.

Assuming the temperature T_e to be a function of the electronic density, we can integrate this expression to:

$$\mathcal{J}_z(n_e) = \int_0^{n_e} dn \frac{n T_e(n)}{n} = \frac{\mu_g m_a}{k_B} \Phi(r),$$

where \mathcal{J}_z is a bijection, as long as the radial density profile ρ_m is a sum of dPIE potentials. Using a self-similar polytropic temperature profile, the \mathcal{J}_z integral only depends on redshift z . Bijections being invertible functions, we may revert the previous equation, thus yielding the idPIE density profile:

$$n_e = \mathcal{J}_z^{-1} \left(\frac{\mu_g m_a}{k_B} \Phi(r) \right).$$

1.2.3 ICM profile optimisation with idPIE profile

Given the n_e ICM electron density, we can compute S_X , the X-ray surface brightness:

$$S_X(x, y, \Delta E) = \frac{1}{4\pi(1+z)^4} \frac{\mu_e}{\mu_H} \int_{\text{l.o.s.}} n_e^2(x, y, l) \Lambda(\Delta E(1+z), T_e, Z) dl,$$

where ΔE is the observed energy band, z is the cosmological redshift of the lens, μ_e and μ_H are respectively the mean molecular weight of electron and hydrogen, and Λ is the normalised cooling function (in $\text{J.m}^3.\text{s}^{-1}$) for an ICM electron temperature T_e and metallicity Z . Here, we assume the metallicity to be constant throughout the cluster $Z = 0.3Z_\odot$.

Once the model surface brightness map computed, it is compared to observations of *Chandra* or *XMM-Newton* X-ray satellites.

Note: TODO: See section on statistics for more details.

1.3 Tutorial

1.3.1 Use idPIE X-ray profiles.

To use idPIE profiles, one must choose which dPIE profiles are considered to trace the X-ray signal. The idPIE profiles use the same parameters as the dPIE profiles, but convert them into their corresponding hydrostatic ICM density, and computes the expected X-ray signal. The joint optimisation of selected profiles yields additional constraints. In practice, dPIE profiles (id:81) are co-optimised with X-ray using idPIE profiles if keyword X-ray 2 is added to the profile script.

For instance:


```

potential 01
    profile          81
    X-ray            2
    x_centre         0.
    y_centre         0.
    ellipticity      0.5
    angle_pos        0.
    core_radius_kpc  100
    cut_radius_kpc   2500.
    v_disp           1000.
    z_lens           0.3
end
limit 01
    x_centre         1 -10. 5. 0.01
    cut_radius_kpc   1 500. 10000. 100.
end

```

1.4 Potfile

1.4.1 Use potfile keyword for file of potentials optimised together (following a scaling relationship).

For instance:

```

potfile 1
    filein           9 potfile.cat
    zlens            0.3
    type             81
    mag0             20.
    corekpc          0.15
    sigma            3 190. 5.
    cutkpc           3 10. 3.
    slope_FJ         3 1. 0.1
    Zero_point_FP    3 -0.6 0.03
    slope_SB         3 0.30 0.02
    Factor_Re        3 2. 0.35
    vdscatter        0 0. 0.
    rcutscatter      0 0. 0.
    pivot_sigma      2.
    pivot_mu         20.
end

```