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`.

CHAPTER

ONE

CONTENTS

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 Elìasdòttir et al. (2007, Appendix A) . It is identified in `lenstool` by id: `81`.

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

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

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:

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

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

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

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

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

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:

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

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:

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

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:

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

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 $\rm J.m^3.s^{-1}$) for an ICM electron temperature T_e and metallicity Z. Here, we assume the metallicity to be constant throughout the cluster $Z = 0.3 Z_\odot$.

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 O1
        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 O1
        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
```