Reconstruction of mass profiles in disc-like galaxies based on its properties of lensing and rotational curves

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Universidad Nacional de Colombia
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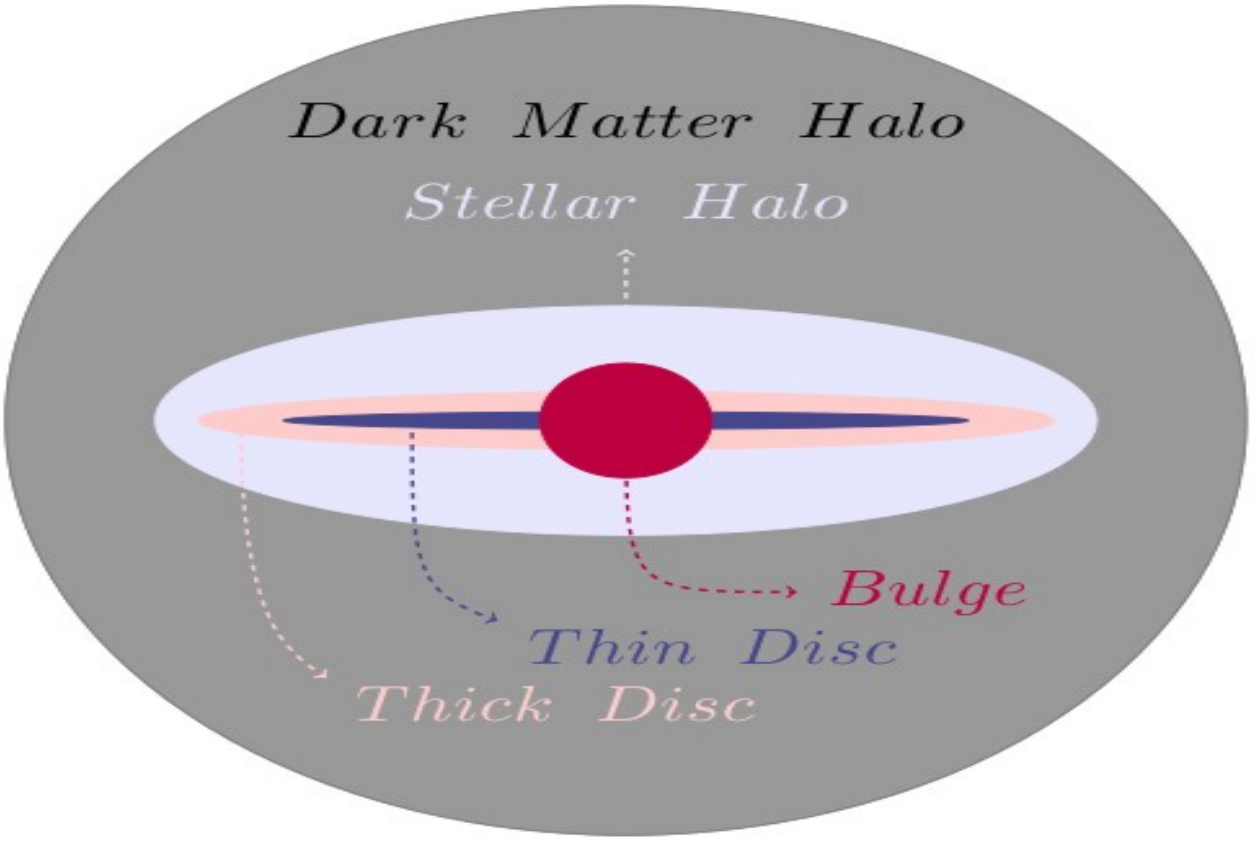
Galactic Dynamics



Galactic Dynamics

$$\nabla^2 \Phi = 4\pi G \rho$$

$$\rho = \sum_{i=1}^{N} \rho_i \qquad \Longleftrightarrow \qquad \phi = \sum_{i=1}^{N} \phi_i$$

(1) $$V_c^2 = \sum_{i=1}^{N} V_{c(i)}^2$$

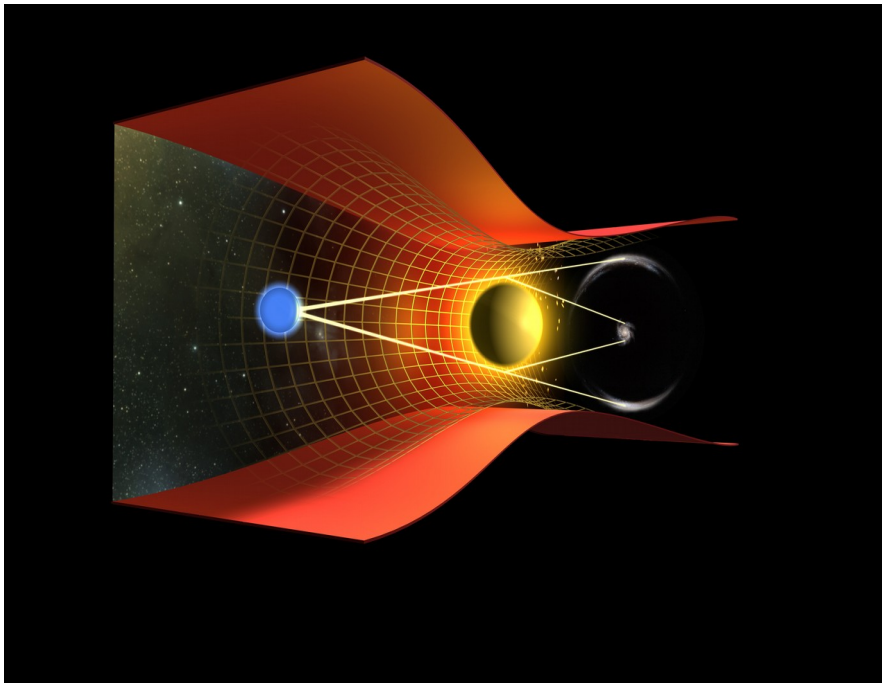
Gravitational Lensing Effect (GLE)

$$\vec{\beta} = \vec{\theta} - \nabla_{\vec{\theta}} \psi(\vec{\theta})$$

Lens equation

$$\kappa = \frac{\Sigma}{\Sigma_{crit}}, \qquad \Sigma = \sum_{i=1}^{N} \Sigma_i \quad (2)$$

$$\psi = 2 \int_0^{\theta} \theta' \kappa(\theta') \ln \frac{\theta}{\theta'} d\theta' \quad (3)$$



With $\theta = \sqrt{\theta_1^2 + \theta_2^2}$

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- Combination of GLE and Galactic Dynamics
- Gallenspy code
- Galrotpy code
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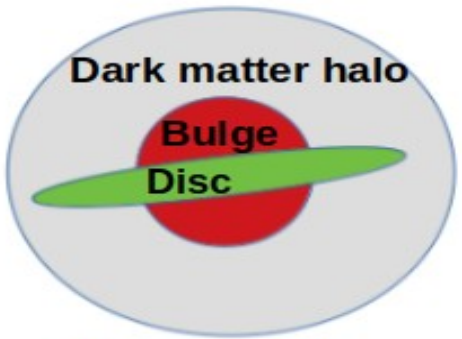
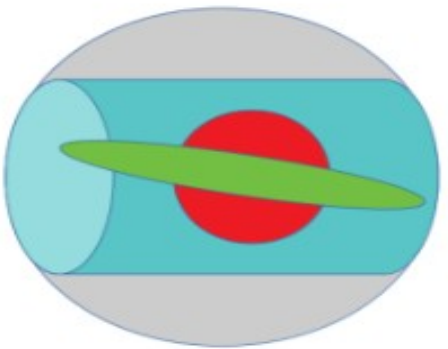
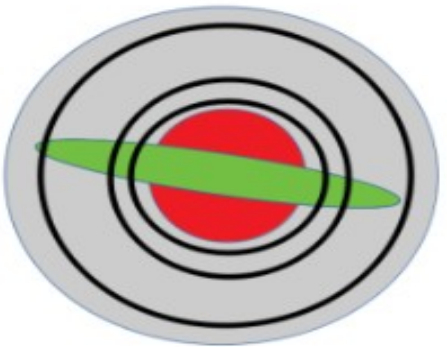
LENSING+DYNAMICS



Observer View



Mass proyected in the GLE



Mass proyected with galactic dynamics

- Taking advantages of each geometry.
- Combining restrictions of both methods.

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Gallenspy Code

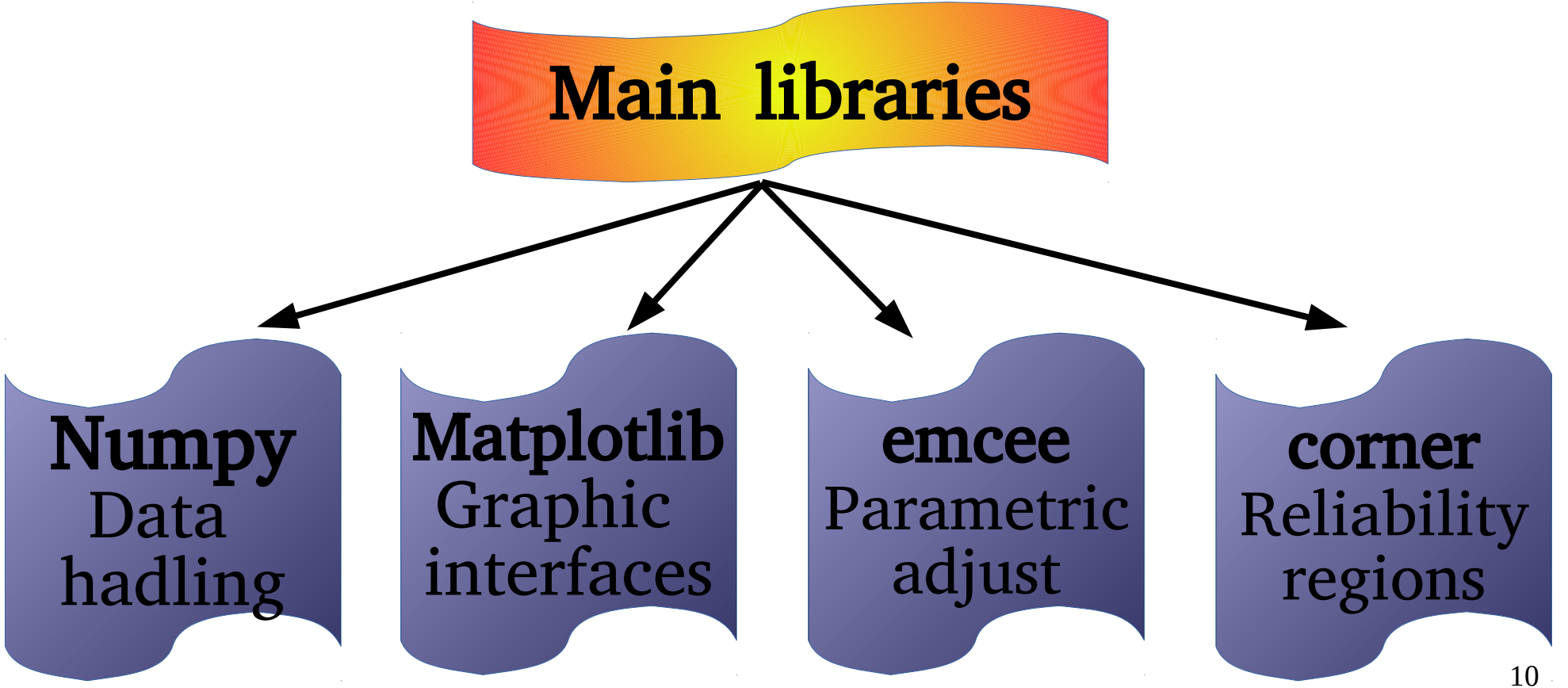
A computational routine developed in python.

Mass reconstructions based on GLE (Grid 100X100).

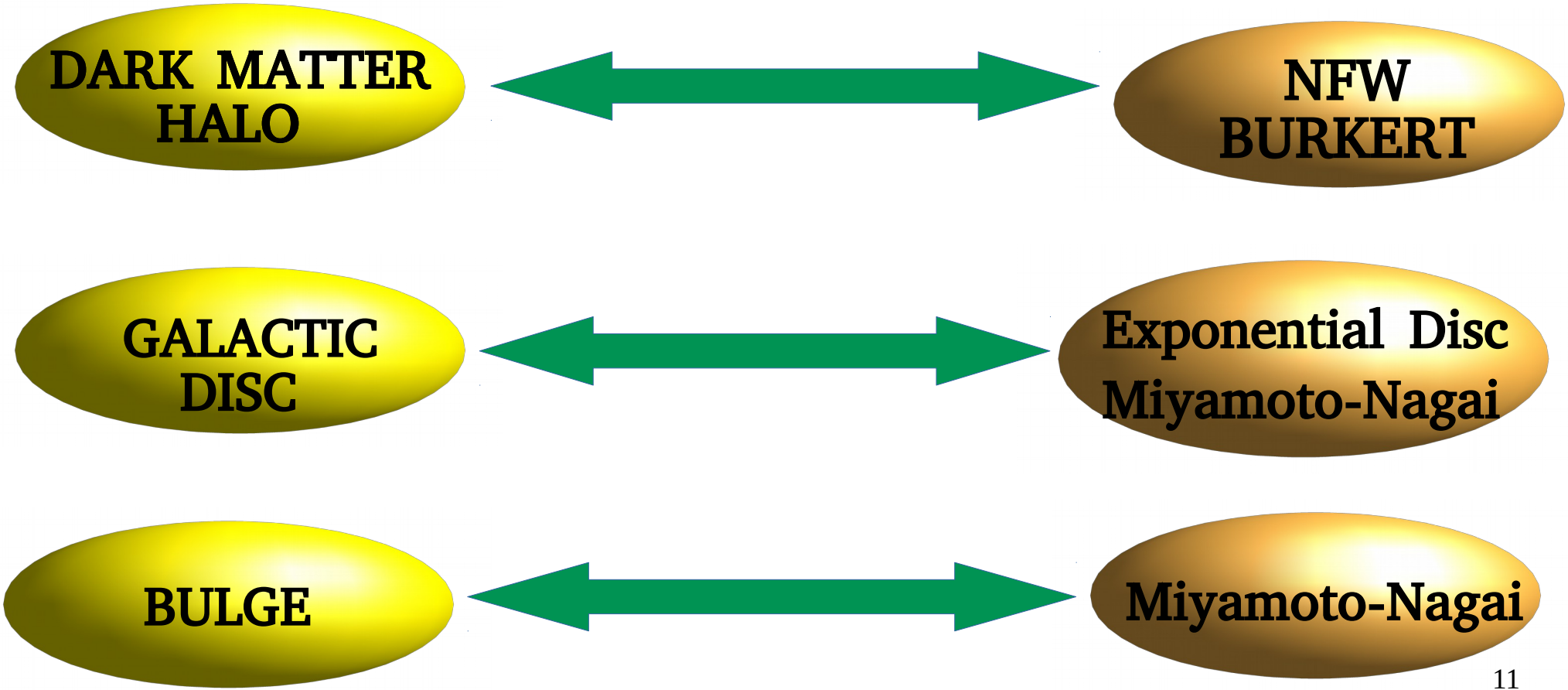
Invert numerically the lens equation.

Estimation in the position of the source.

Gallenspy Code



Gallenspy potentials



Range of Values

Range of values with Gallenspy		
Component	**Range of parameters**	**Units**
Bulge I	$a = 0$	kpc
	$0.0 < b < 0.5$	kpc
	$0.1 < M < 1.0$	$10^{10} M_{\odot}$
Bulge II	$0.01 < a < 0.05$	kpc
	$0.5 < b < 1.5$	kpc
	$1 < M < 5$	$10^{10} M_{\odot}$
Disc thin	$1 < a < 10$	kpc
	$0.1 < b < 1.0$	kpc
	$0.5 < M < 1.5$	$10^{11} M_{\odot}$
Disc thick	$1 < a < 10$	kpc
	$0.1 < b < 15.0$	kpc
	$0.5 < M < 1.5$	$10^{11} M_{\odot}$
Exponential Disc	$2 < h_r < 6$	kpc
	$1 < \Sigma_0 < 15$	$10^2 M_{\odot}/pc^2$
Halo NFW	$0.1 < a < 30$	kpc
	$0.1 < M_0 < 10$	$10^{11} M_{\odot}$
Halo Burket	$2 < a < 38$	kpc
	$0.1 < \rho_0 < 10$	$10^6 M_{\odot}/kpc^3$

MCMC-Gallenspy

$$P(p|D,M)=\frac{P(D|p,M)\,P(p|M)}{P(D|M)} \quad (4)$$

σ_{ij} → **Error in observational positions.**

$$X_i^2=\sum_{j=1}^{N}\frac{\left|\theta_{obs}{}^{j}-\theta(p)^{j}\right|}{\sigma_{ij}{}^{2}}$$

$$\prod_{i=1}^{N}\frac{1}{\prod_j \sigma_{ij}\sqrt{2\pi}}\exp\left(\frac{-X_i^2}{2}\right) \quad \text{Likelihood} \quad P(D|p,M)$$

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Galrotpy Code

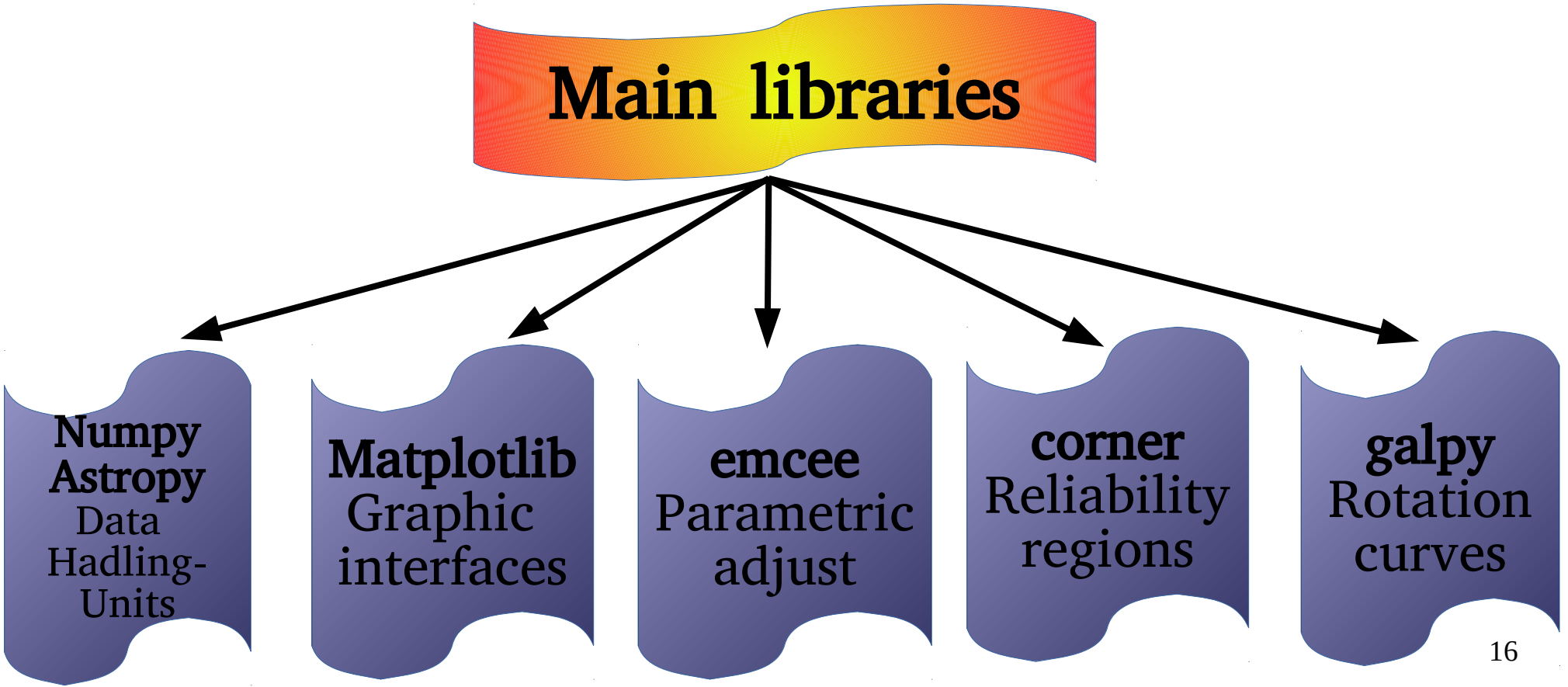
Mass reconstructions based on rotation curves with python.

Same potentials and value ranges of Gallenspy.

Each gravitational contribution is visualized.

The parameters initial set is fit interactively by the user.

Galrotpy Code

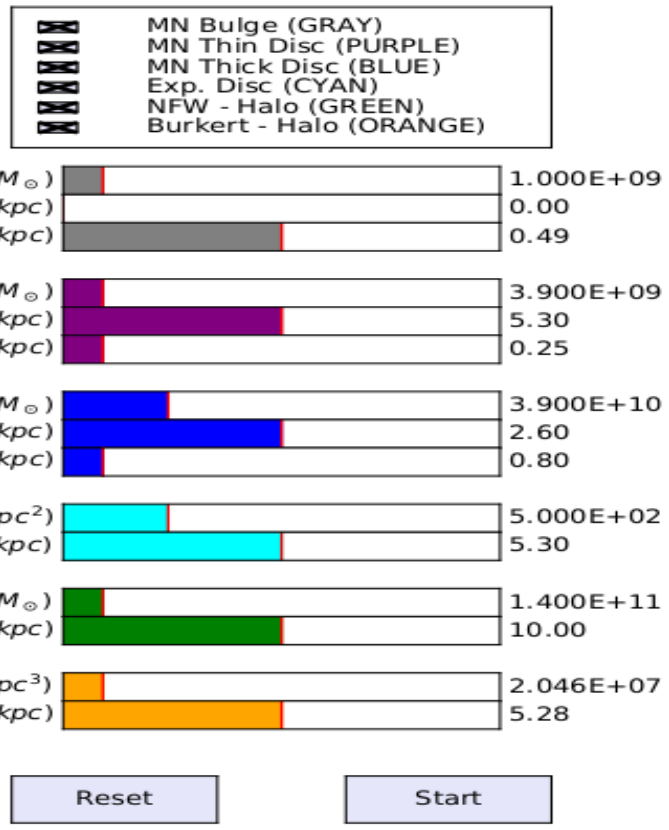


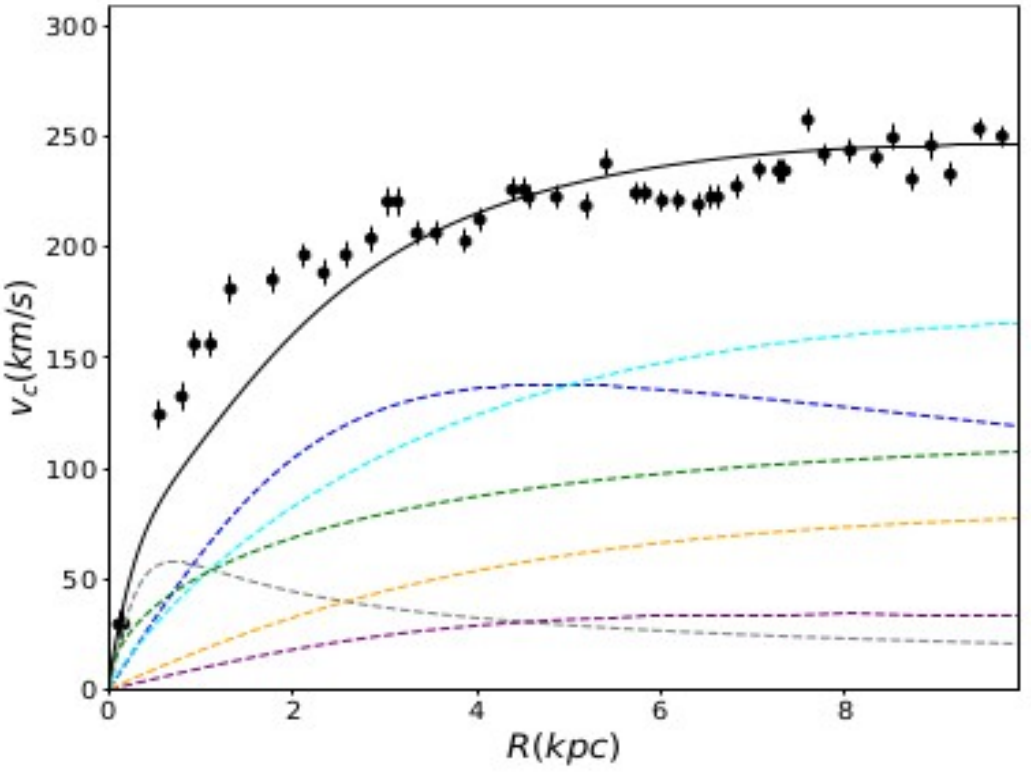
MCMC Equation 4

$$L = \exp\left(-\frac{1}{2} \sum_{i=1}^{N} \left[\frac{\nu_i^{data} - \nu_i^{model}}{\nu_i^{error}} \right]^2 \right) \quad (5)$$

ν_i^{error} → **Error in observational data.**

INTERACTIVE FIT





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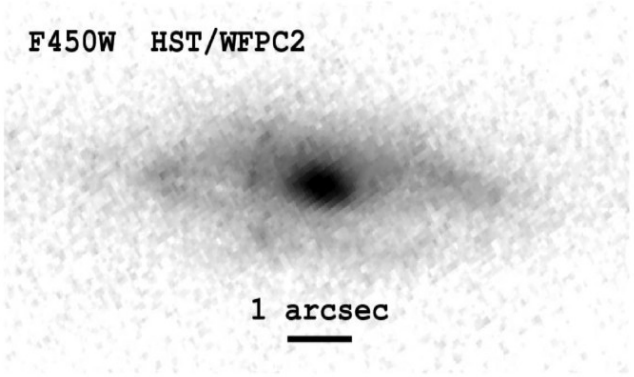
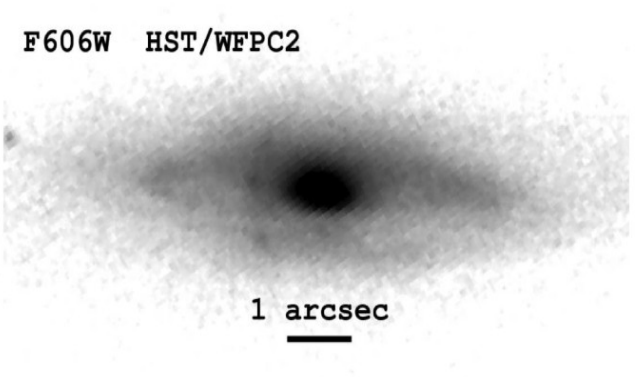
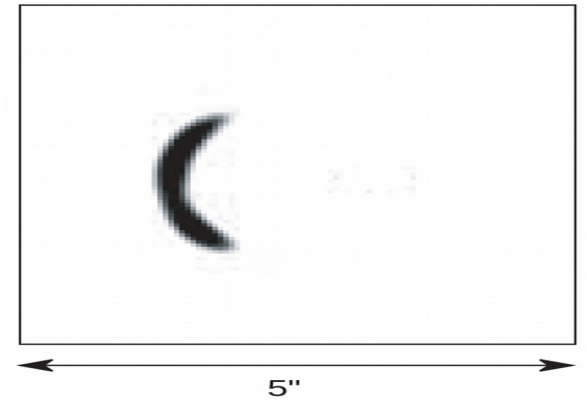
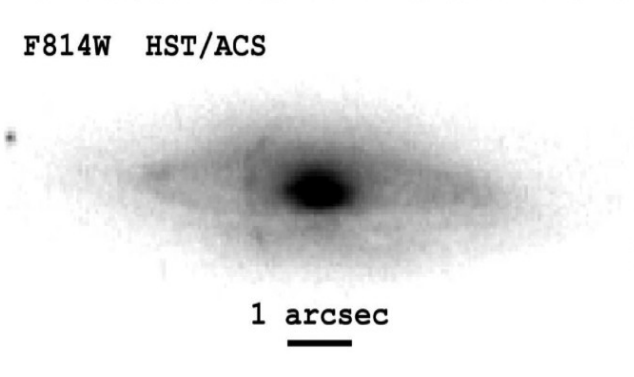
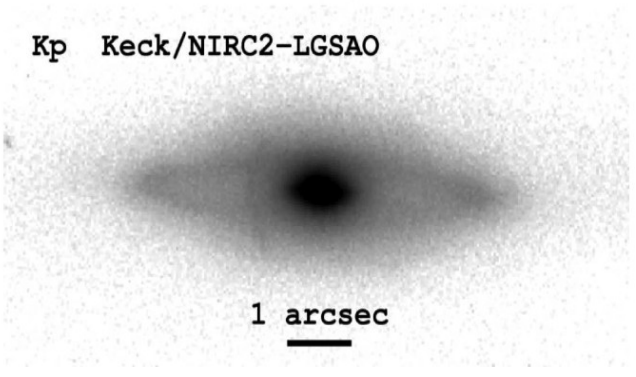
GALAXY J2141

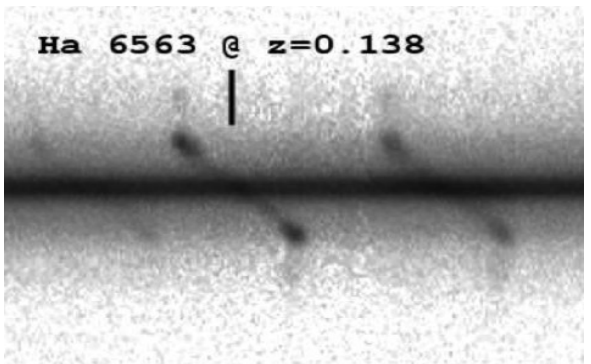






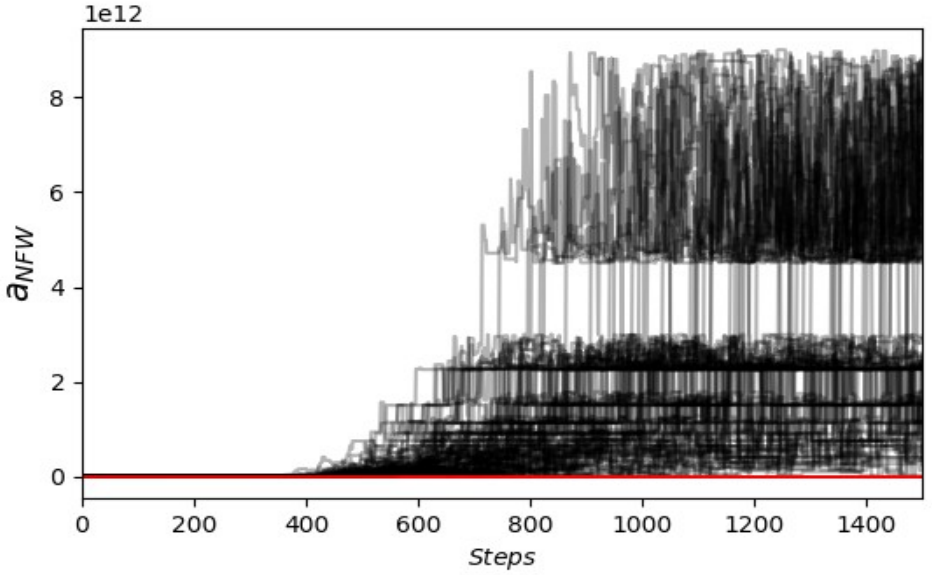


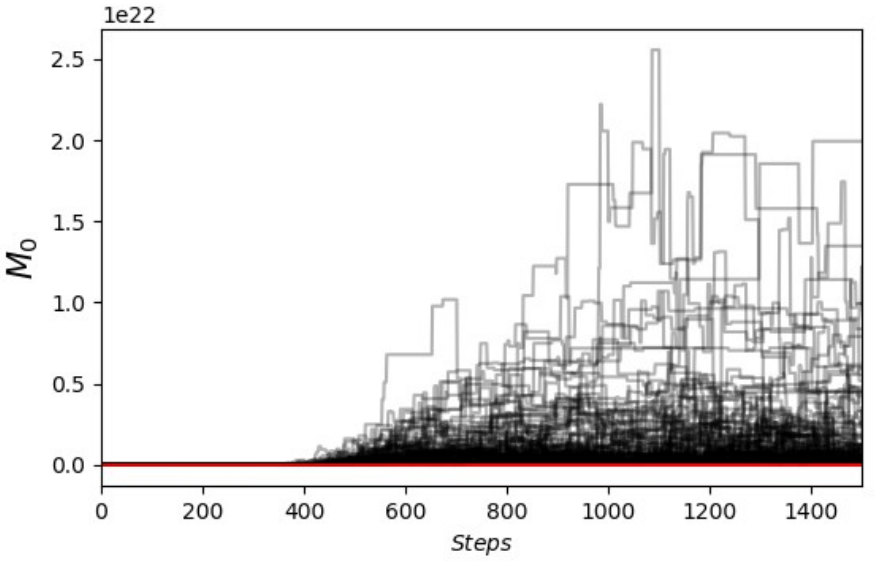




GALROTPY J2141

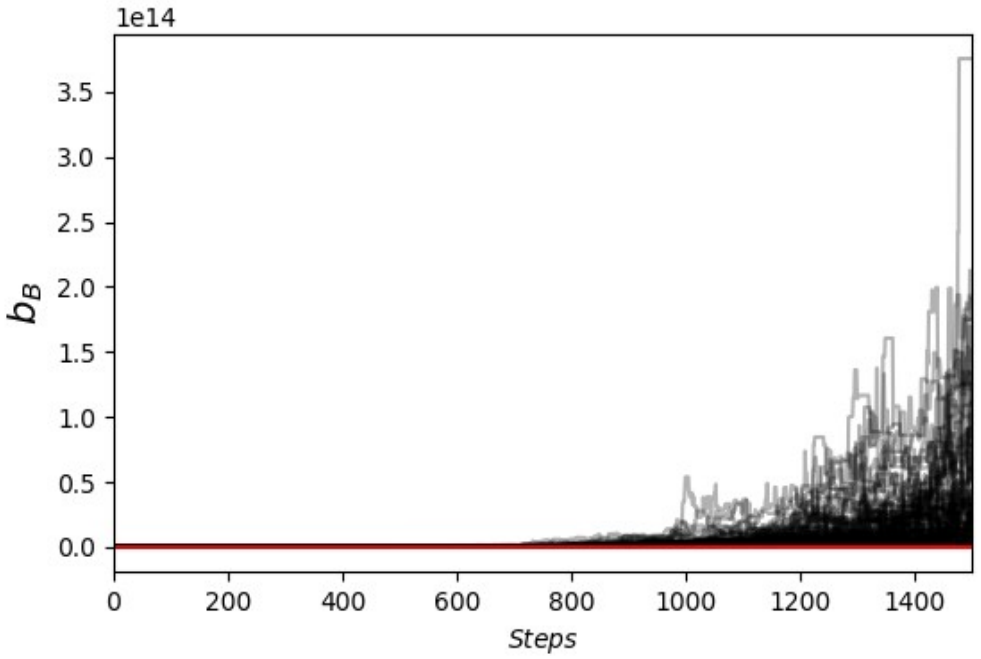
NFW Profile

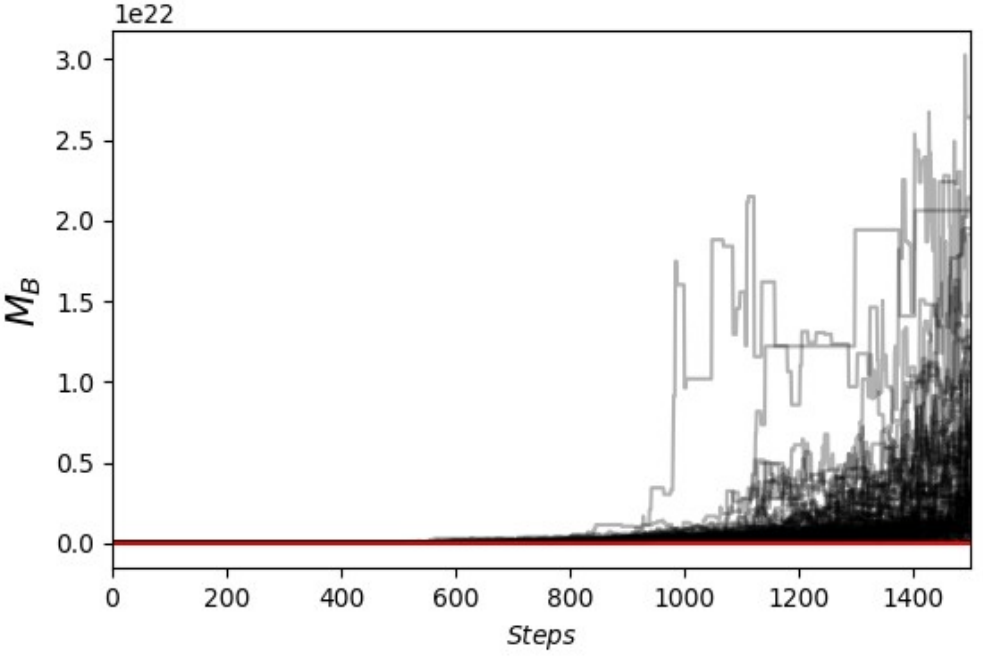




GALROTPY J2141

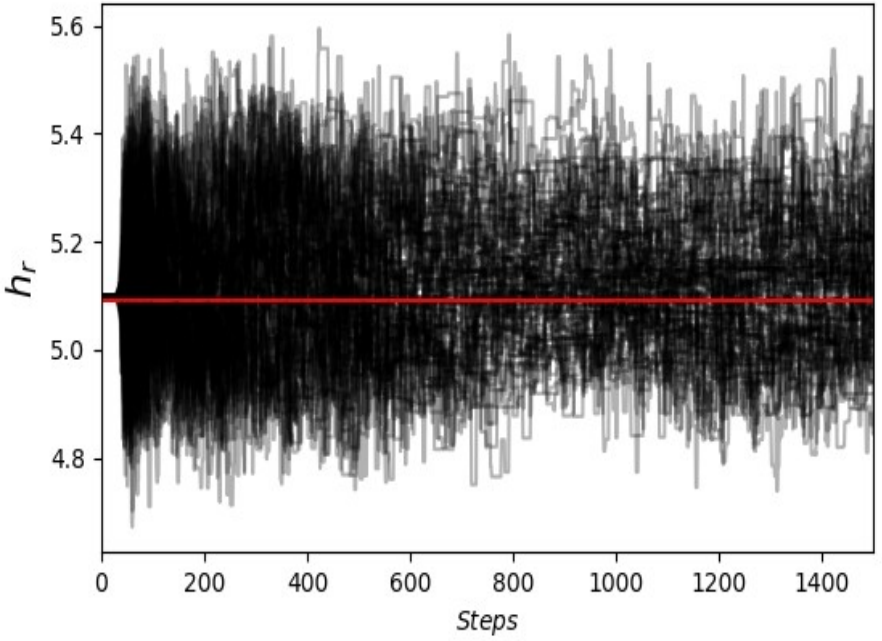
MN Profile

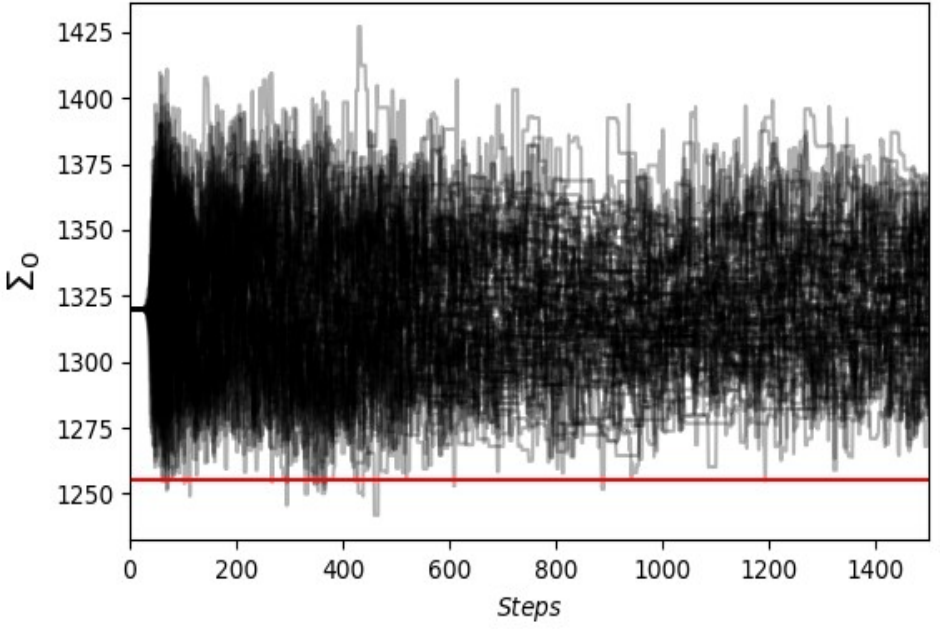




GALROTPY J2141

Exponential Disc Profile





DEGENERACY PROBLEM

- Gravitational dominance of disc.
- Difficult to know the gravitational contribution of each mass component.
- Combine geometries and restrictions of GLE and galactic dynamics.

GALLENSPY J2141

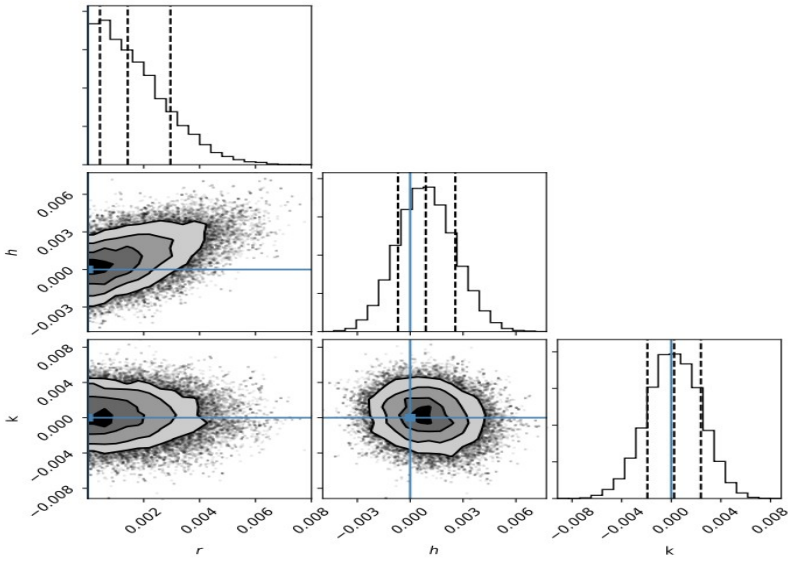
- Cosmological model ΛCDM.

- Cosmological distance: $D_d = 497.6\ Mpc$,

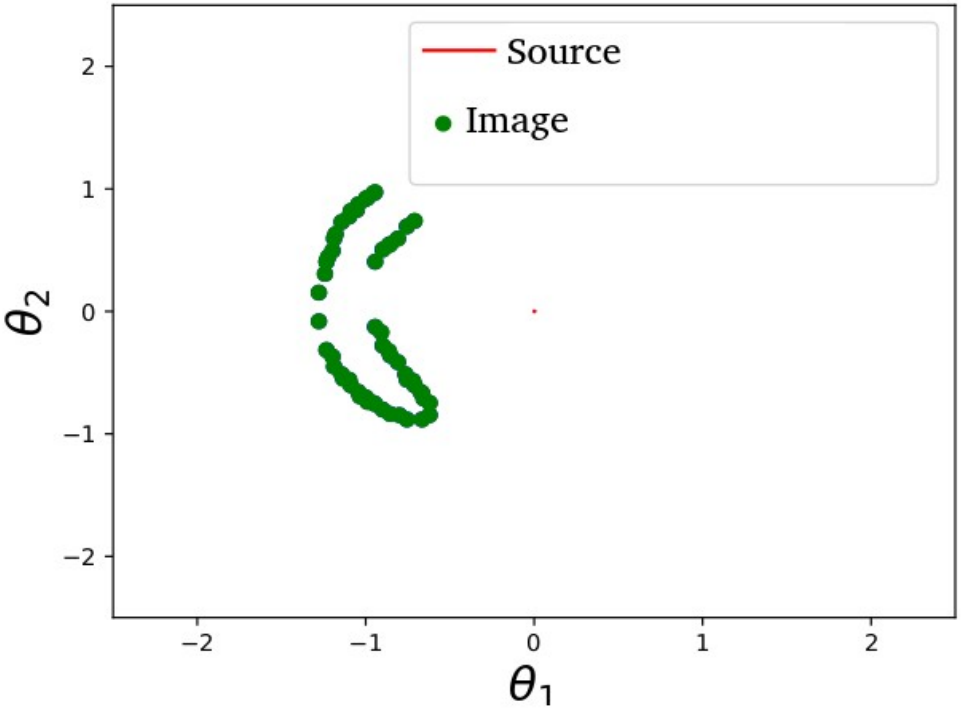
  $D_s = 1510.2\ Mpc$ and $D_{ds} = 1179.6\ Mpc$

- Circular source in strong lensing formalism.

GALLENSPY J2141

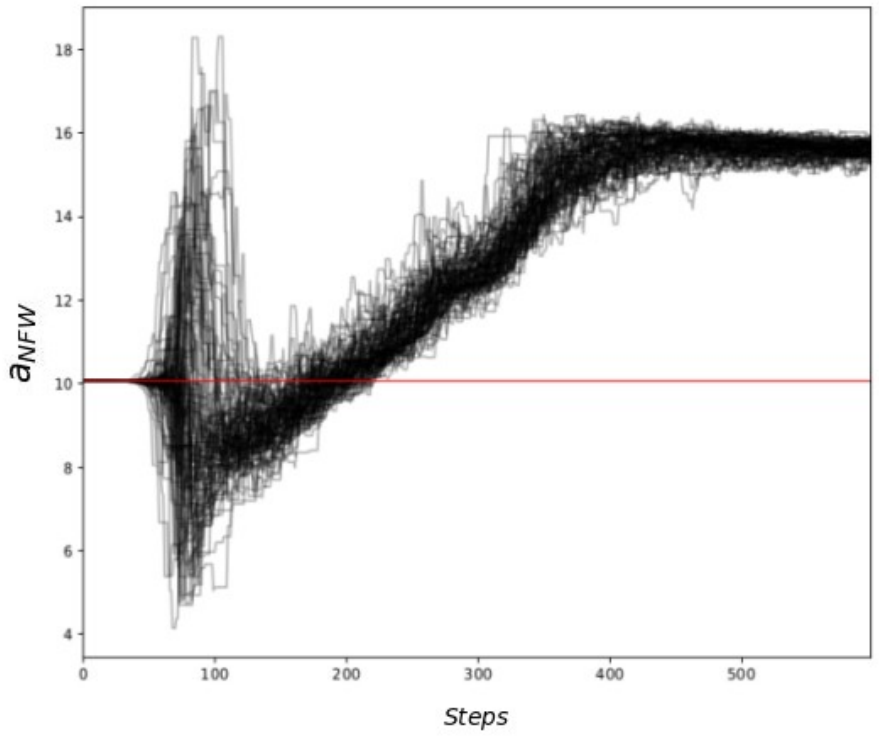


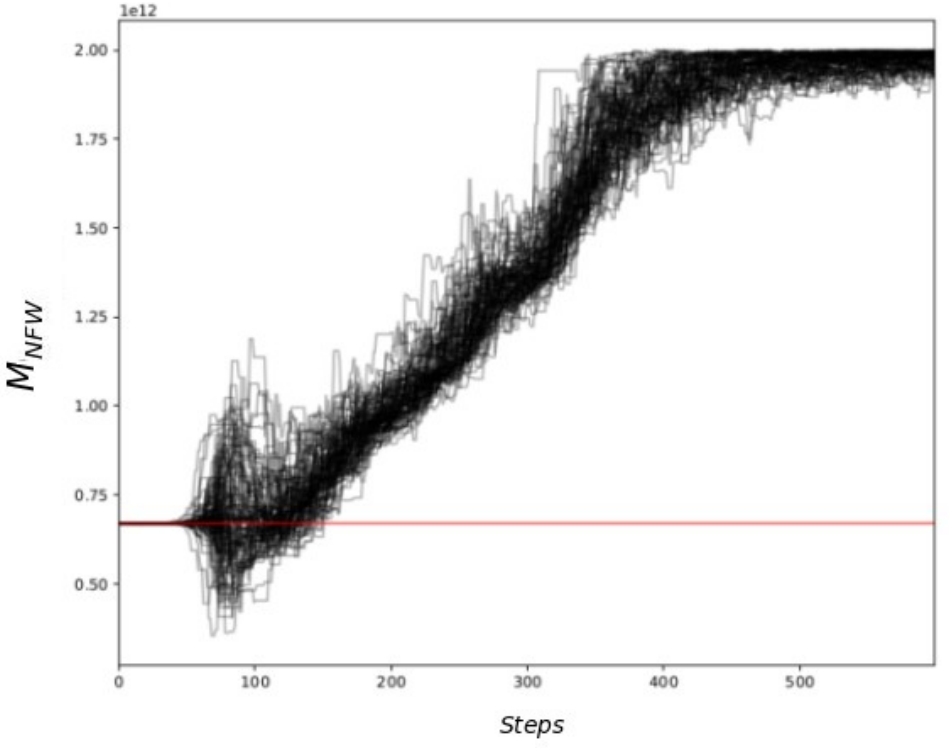
Parameter	68%	95%
r $(X10^3 \text{arcs})$	$1.42^{+1.5}_{-0.9}$	$1.42^{+3.21}_{-0.135}$
h $(X10^4 \text{arcs})$	$8.85^{+16.75}_{-1.576}$	$8.85^{+3.333}_{-3.065}$
k $(X10^4 \text{arcs})$	$2.294^{+2.15}_{-0.215}$	$2.294^{+4.13}_{-0.435}$



GALLENSPY J2141

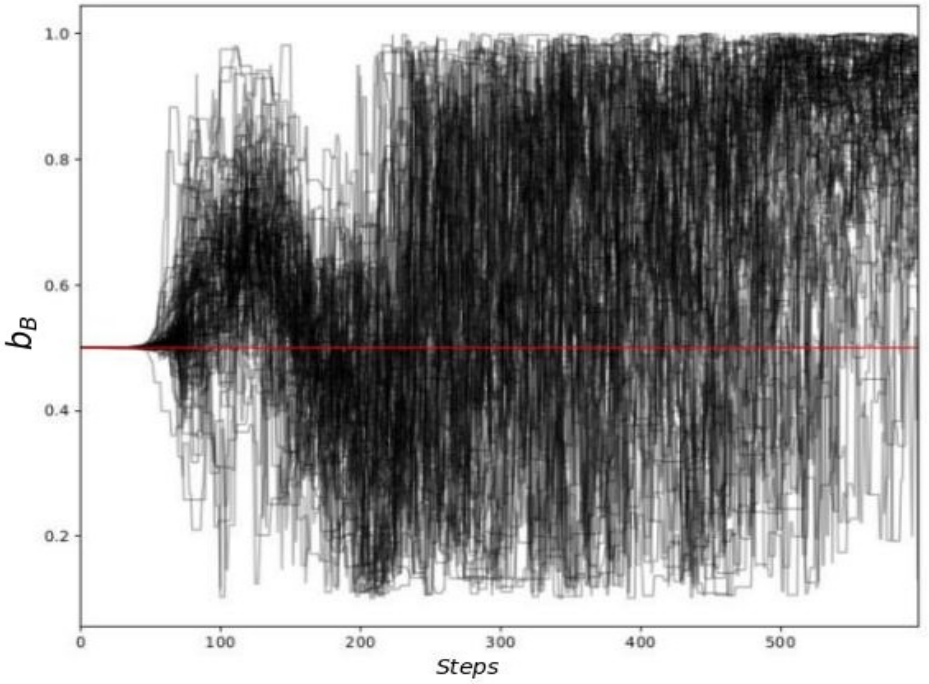
NFW Profile

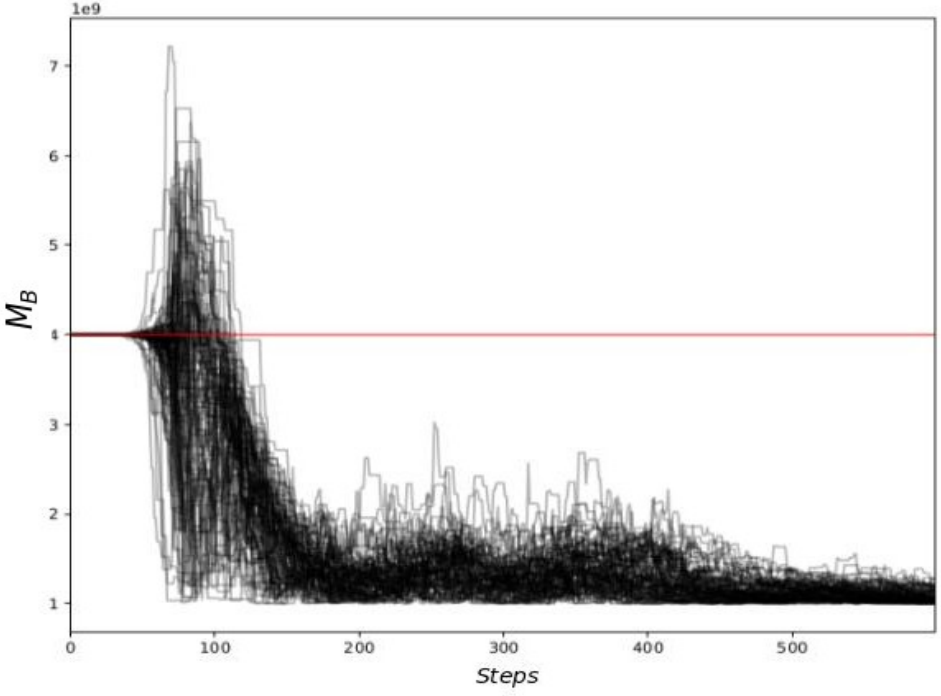


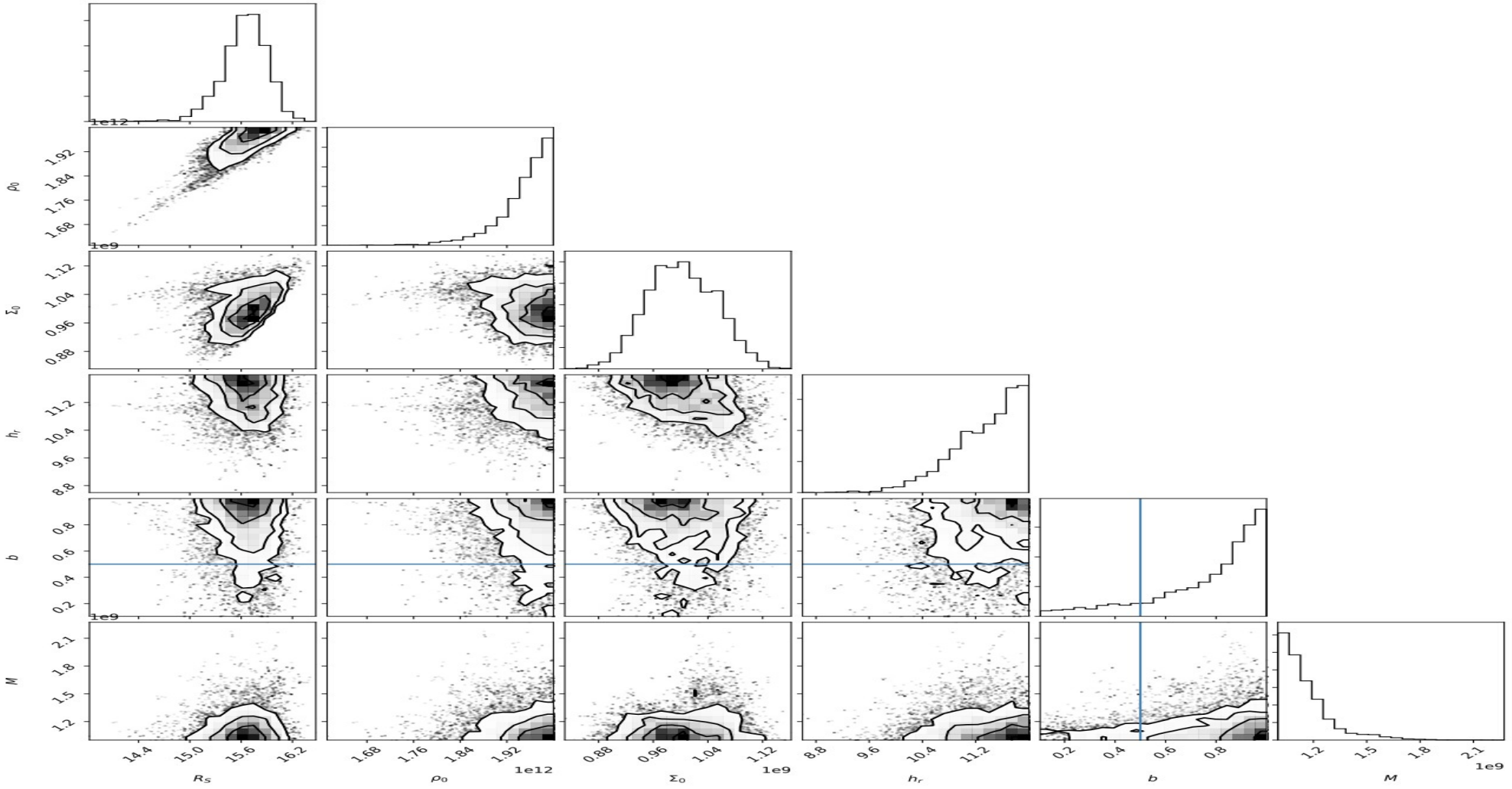


GALLENSPY J2141

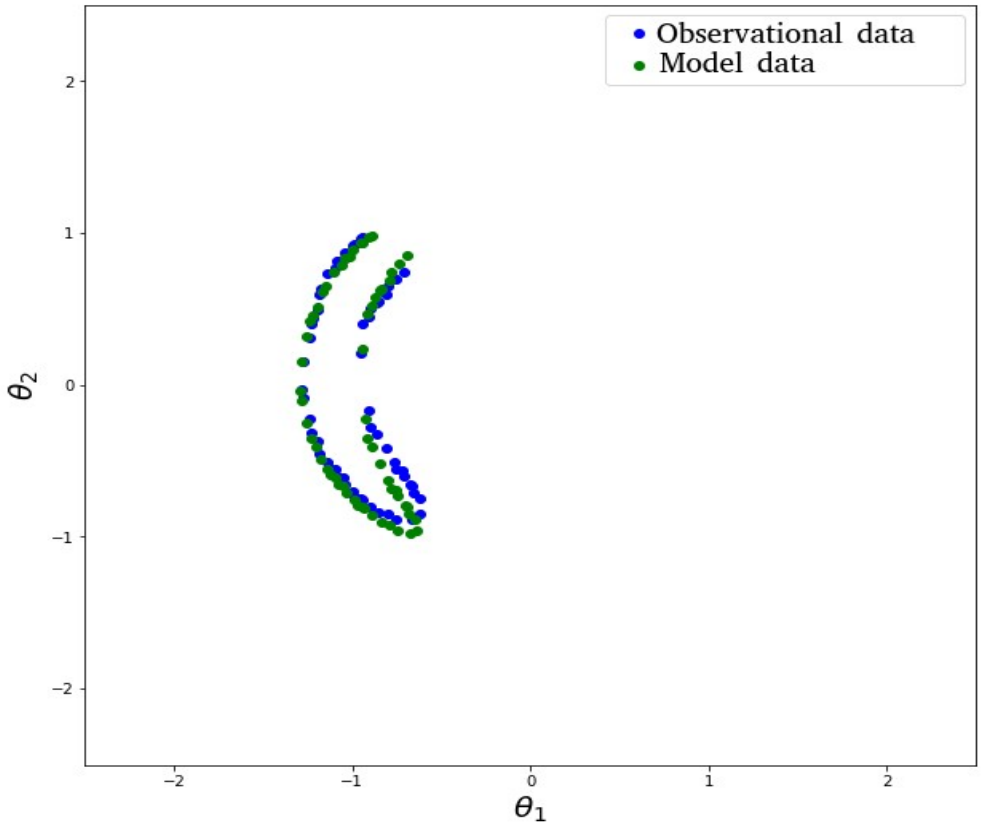
MN Profile

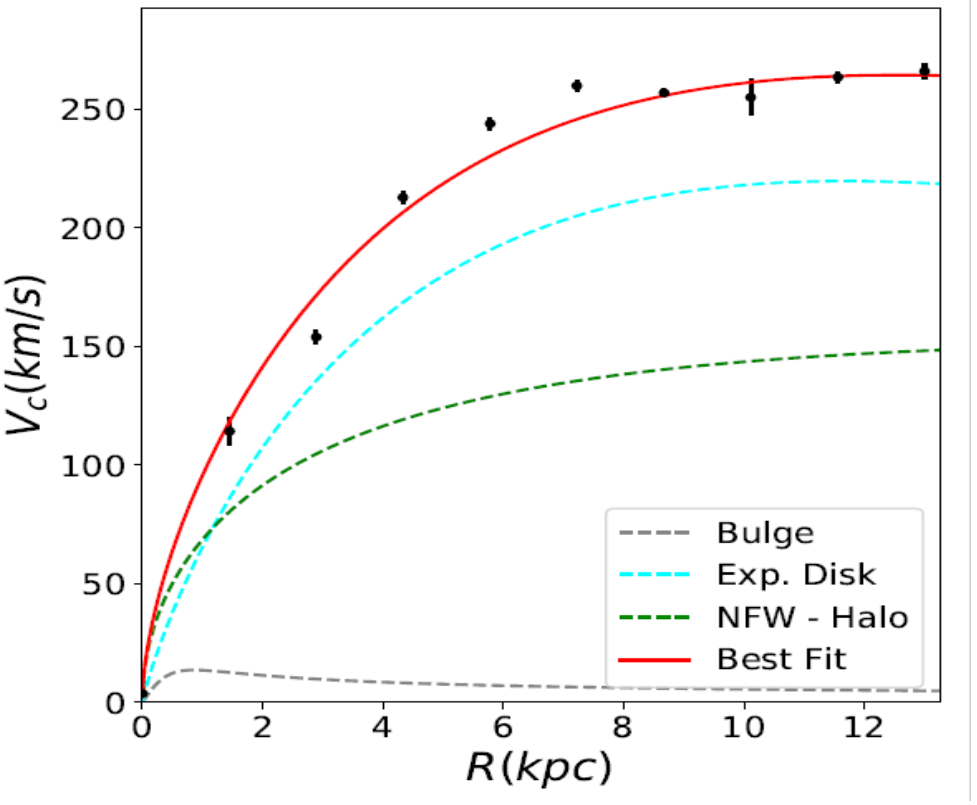





1e12
1.92
1.84
1.76
1.68
ρ_0
1e9
1.12
1.04
0.96
0.88
Σ_0
11.2
10.4
9.6
8.8
h_r
0.8
0.6
0.4
0.2
b
1e9
2.1
1.8
1.5
1.2
M
14.4
15.0
15.6
16.2
R_S
1.68
1.76
1.84
1.92
1e12
ρ_0
0.88
0.96
1.04
1.12
1e9
Σ_0
8.8
9.6
10.4
11.2
h_r
0.2
0.4
0.6
0.8
b
1.2
1.5
1.8
2.1
1e9
M

FIT J2141


Observational data
Model data
θ_1
θ_2

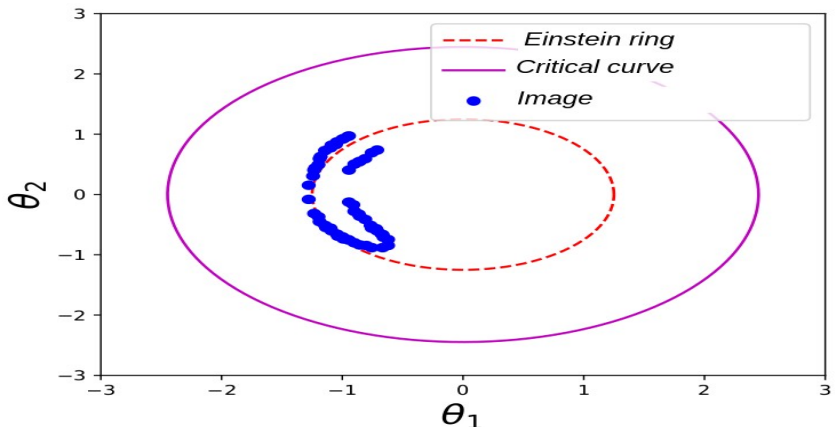

Bulge
Exp. Disk
NFW - Halo
Best Fit
$V_c(km/s)$
$R(kpc)$

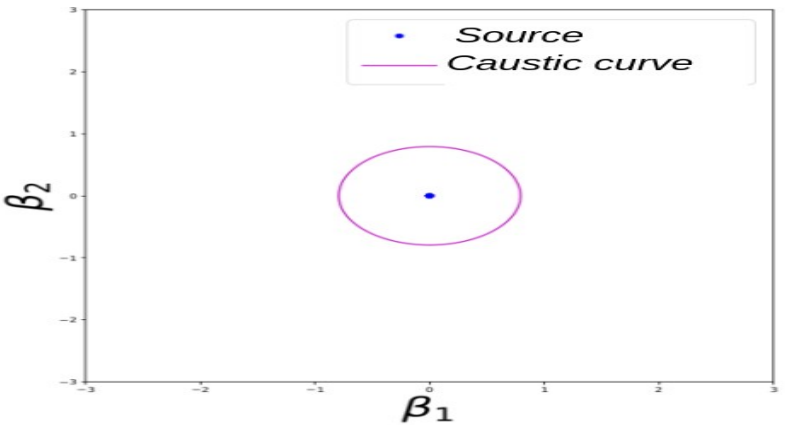
FIT J2141

$$\theta_{crit} = 2.477^{+0.001}_{-0.001}\, arcs$$

$$\theta_{Eins} = 1.250^{+0.45}_{-0.45}\, arcs$$

Parameter	68%	95%
NFW		
a (X10kpc)	$1.563^{+0.007}_{-0.010}$	$1.563^{+0.020}_{-0.036}$
m_0 $(X10^{11}$ $M_\odot)$	$9.938^{+2.96}_{-2.13}$	$9.938^{+0.048}_{-0.630}$
Exponential Disc		
h_r (Kpc)	$11.556^{+0.046}_{-0.310}$	$11.556^{+0.055}_{-1.276}$
Σ_0 $(X10^9$ $M_\odot$ $pc^{-2})$	$1.015^{+0.117}_{-0.044}$	$1.015^{+0.291}_{-0.087}$
Miyamoto-Nagai		
b (Kpc)	$0.972^{+0.098}_{-0.293}$	$0.972^{+0.111}_{-0.782}$
M $(X10^9$ $M_\odot)$	$1.044^{+2.367}_{-0.035}$	$1.044^{+2.956}_{-0.043}$





FIT J2141

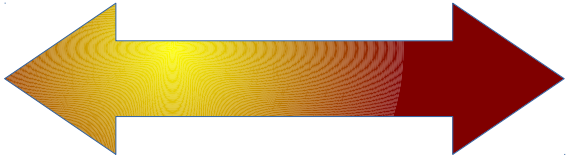
Parameter	$Log_{10}\left(\frac{\mathrm{M}}{\mathrm{M}_{\odot}}\right)$
M_{crit}	$11.172^{+0.336}_{-0.135}$
Mbar_{crit}	$10.672^{+0.325}_{-0.618}$
M_{Eins}	$10.860^{+0.462}_{-0.160}$
Mbar_{Eins}	$10.381^{+0.395}_{-0.868}$
M_{curv}	$11.1808^{+0.336}_{-0.145}$
Mbar_{curv}	$10.679^{+0.418}_{-0.305}$

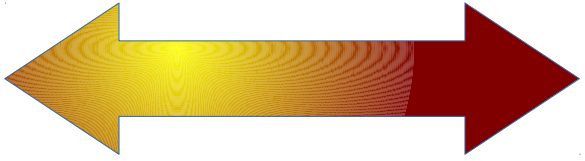
Component of the galaxy	$log_{10}\left(\frac{M}{M_{\odot}}\right)$
Bulge	$9.400^{+0.528}_{-0.256}$
Disc	$10.656^{+0.360}_{-0.142}$
Dark Matter Halo	$11.016^{+0.966}_{-0.131}$

Mass within the radius of the rotation curve reported by Dutton et al.

$$Log_{10}\left(\frac{\mathrm{Mbar}}{\mathrm{M}_{\odot}}\right) = 10.99^{+0.11}_{-0.25}$$

Other tested cases

J1331  Trick et. al.

HE 0435  Courbin et. al.

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CONCLUSIONS

- Gallenspy as a efficient tool for mass profiles reconstructions.

- The great advantages of combining lensing and Galactic dynamics with Galrotpy and Gallenspy.

- Significant results of mass models with spherical symmetry.

CONCLUSIONS

- Future improvements for Gallenspy: mass profiles, superficial brightness functions, temporary cosmological delays.

- Advantages of performing visuals fitting in these routines.

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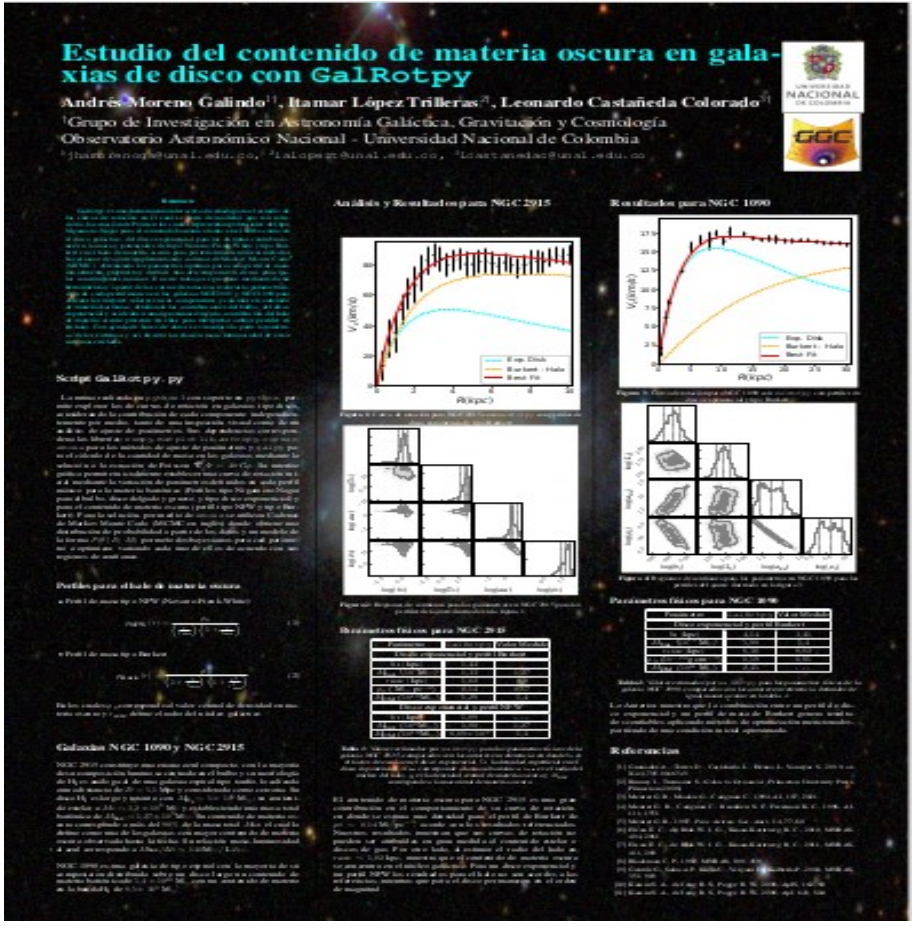
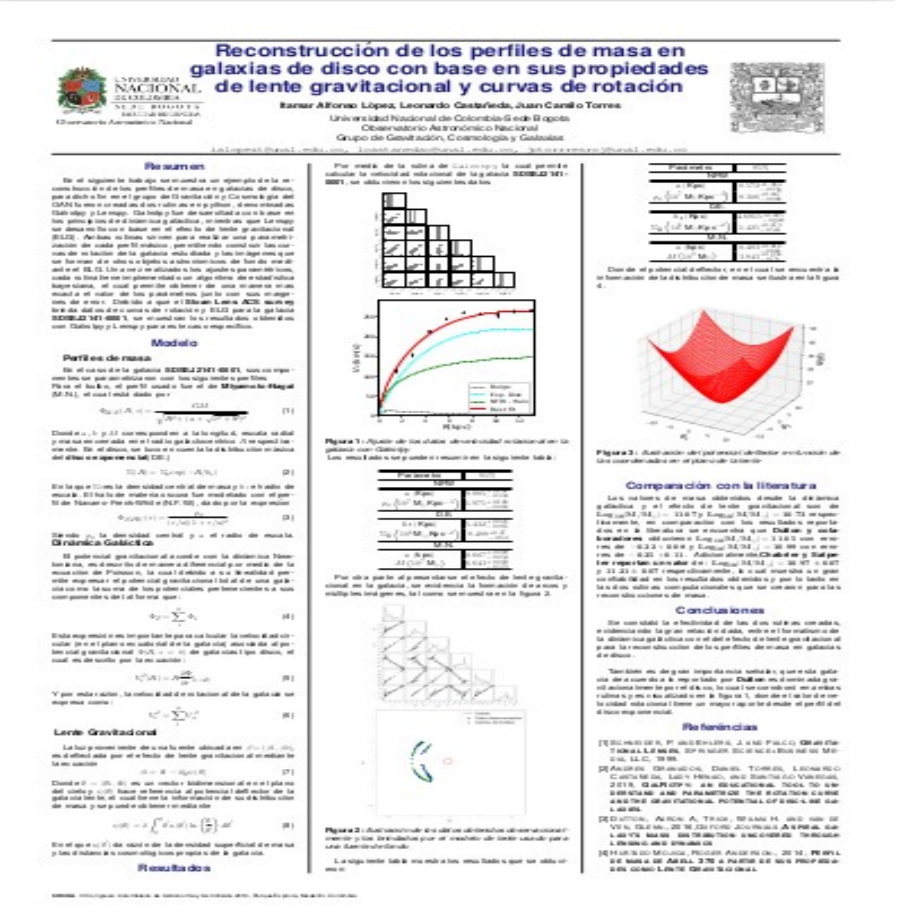
COCOA 2019


Estudio del contenido de materia oscura en galaxias de disco con GalRotpy
Andrés Moreno Galindo[1], Itamar López Trilleras[2], Leonardo Castañeda Colorado[1]
[1]Grupo de Investigación en Astronomía Galáctica, Gravitación y Cosmología
Observatorio Astronómico Nacional - Universidad Nacional de Colombia
Análisis y Resultados para NGC 2915
Resultados para NGC 1090
Script GalRotpy.py
Perfiles para el halo de materia oscura
Galaxias NGC 1090 y NGC 2915
Parámetros físicos para NGC 2915
Parámetros físicos para NGC 1090
Referencias


Reconstrucción de los perfiles de masa en galaxias de disco con base en sus propiedades de lente gravitacional y curvas de rotación
Itamar Alfonso López, Leonardo Castañeda, Juan Camilo Torres
Universidad Nacional de Colombia-Sede Bogotá
Observatorio Astronómico Nacional
Grupo de Gravitación, Cosmología y Galaxias
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Lente Gravitacional
Resultados
Comparación con la literatura
Conclusiones
Referencias

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GalRotpy: a tool to parametrize the gravitational potential of disc-like galaxies ☆

Andrés Granados [a, b], Daniel Torres [b], Leonardo Castañeda [b], Lady Henao [c], Santiago Vanegas [b]

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Thanks