Axisymmetric orbit-based models of dwarf spheroidal galaxies

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Aims: Developing a reliable method for measuring the mass, flattening and scale radius of an axisymmetric dwarf spheroidal galaxy.
Methods: We test the Schwarzschild's orbit superposition method on a composite mock dwarf spheroidal galaxy.
Results: We recover the characteristic parameters of the mock galaxy, even if the underlying mass distribution is unknown.

1. Dwarf galaxies and dark matter

- Dwarf spheroidal galaxies are believed to contain large amounts of dark matter.
- A precise measurement of the amount of dark matter in these systems is difficult: we can only obtain accurate line-of-sight velocities for its stars to derive the mass content.

2. Schwarzschild modelling

- Orbits are used as building blocks of a system.
- Given a potential, a complete set of orbits is integrated and for each orbit the predicted observables are stored in an orbit library.
- Different potential = Different orbit library

The library from which a combination of weighted orbits matches the observations the best, corresponds to the best-fit potential.

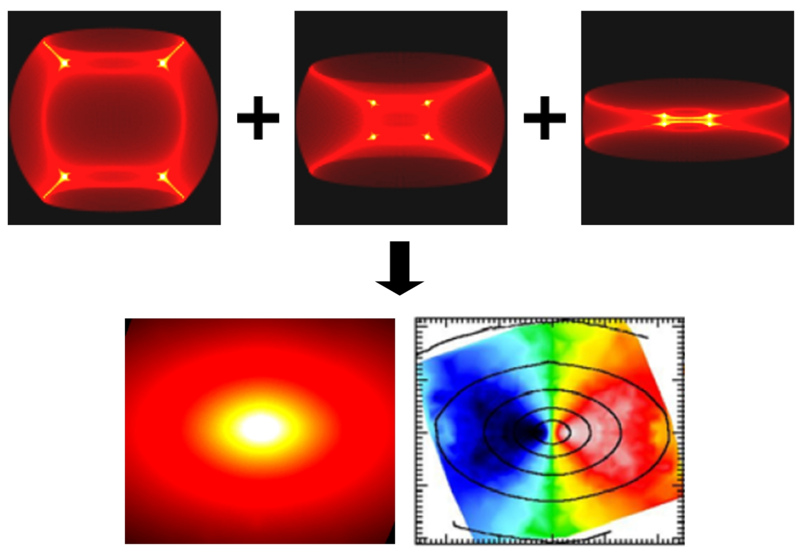

Figure 1: Schwarzschild modelling (Cappellari, 2015). Top: projected paths of individual orbits. Bottom: the combined surface brightness and kinematics of the modelled galaxy.

3. The mock dwarf spheroidal galaxy

Our mock galaxy has properties similar to the Sculptor dwarf spheroidal galaxy. We give it flattened luminous and dark matter components. Such a system can be generated from a simple analytic distribution function (Evans, 1993).

Global Potential:
Axisymmetric logarithmic potential:
- Mass parameter: $v_0 = 20$ km/s
- Core radius: $R_c = 1$ kpc
- Potential flattening: q = 0.8

Stellar density:
The stellar density component has the same flattening and core radius as the global potential.

Velocity dispersion:
In this composite system, the projected line-of-sight velocity dispersion is independent of the viewing angles. For our choices of parameters it is equal to 10.7 km/s.

4. Observing the mock galaxy

- The theoretical surface brightness of the mock galaxy is observed in 99x99 positional bins (light bins) on the sky. We use a 3x3 kpc field of view.
- Similarly, 9x9 kinematic bins are used for the first four velocity moments. Gaussian measurement errors (with amplitude 2km/s) are added to the line-of-sight velocities of the N stars in our field of view (Breddels et al. 2013).
- We use either $N=10^4$ or $N=10^5$.

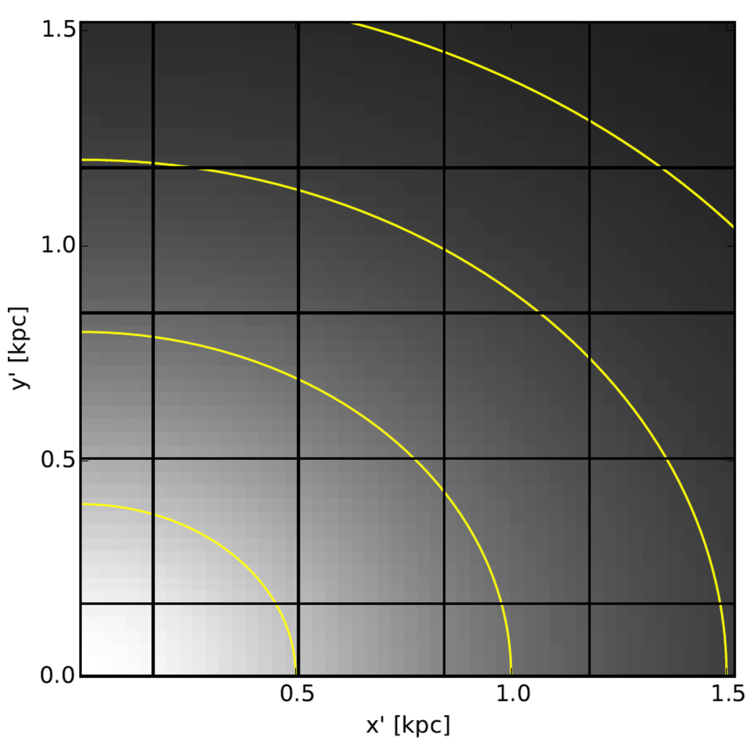

Figure 2: The observed surface brightness of our mock galaxy in the case of an edge-on view. We only show the positive quadrant of our field of view. Full yellow contours visualise the constant flattening in the light. The black horizontal and vertical lines show the boundaries of the kinematic bins.

5. Results 1: Recovery of the characteristic parameters of the mock dwarf spheroidal galaxy

We here assume that the true potential functional form and the edge-on view are known. We fit the light in all light bins and the velocity moments in all kinematic bins. We fix R_c to its true value and recover the input parameters q and v_0.

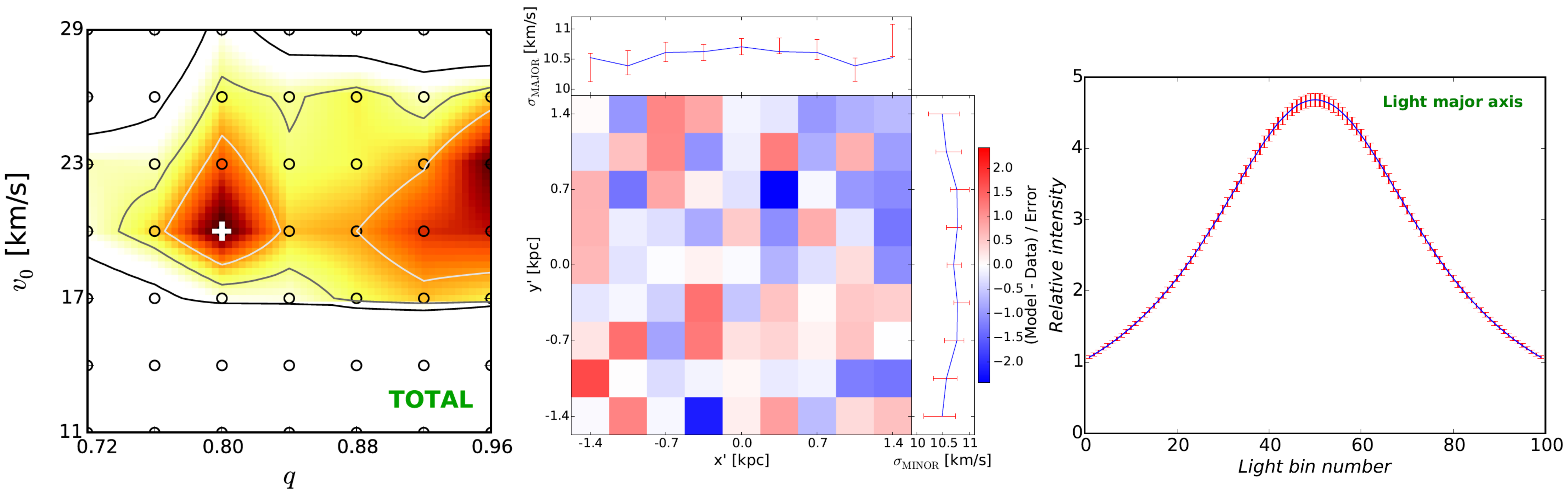

Figure 3. Left: 1-,2- and 3-sigma probability contours after fitting our mock data consisting of 10^5 stars inside our field of view. The coloured landscape shows the interpolated log-likelihood in between the evaluated models (open circles). Middle: The best-fit model's velocity dispersions in all kinematic bins, compared to the mock observations. On top and on the right, the data along the major and minor axis are shown respectively. Right: The best-fit model's light profile [arbitrary unit] along the major axis. We assumed a relative error of 2% in each of the light bins. The light profile can almost always be fitted well.

6. Results 2: Recovery of the mass, scale radius and flattening in modified NFW models.

We also constrain the characteristic parameters while assuming an axisymmetric NFW potential functional form for the models (Vogelsberger et al. 2008), given an edge-on view.

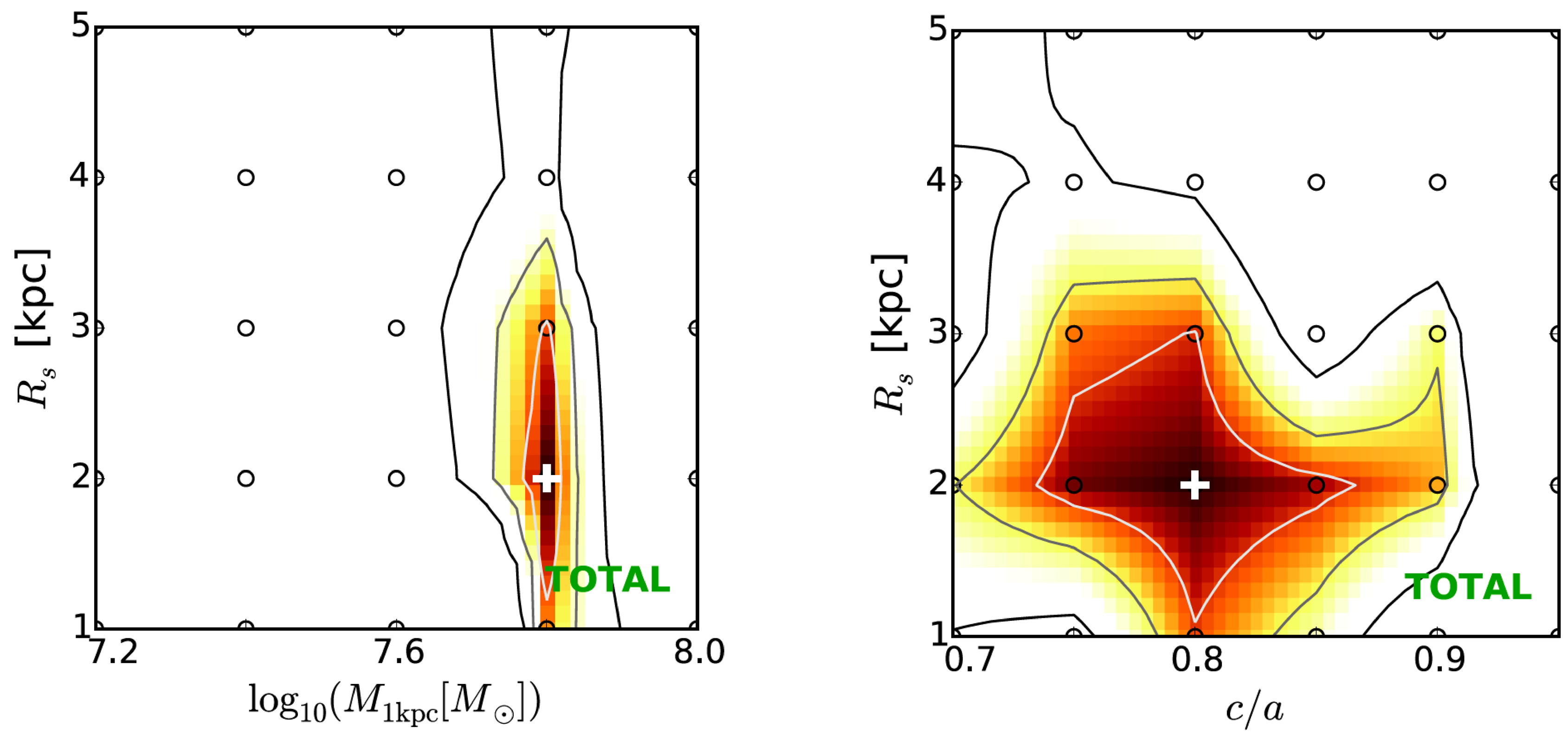

Figure 4: Probability contours after fitting our mock data consisting of 10^4 stars. The correct characteristic parameters are recovered.
Left: mass vs. scale radius.
Right: flattening vs. scale radius.

Given that the functional form here differs from the true mass distribution, we had first determined the closest modified NFW model. Its parameters are $M_{1kpc} = 10^{7.7}$ solar masses, $Rs \geq 2$ kpc and c/a=0.78 in the range 0.5 - 2.0 kpc from the center. We thus recovered these values when applying Schwarzschild modelling.

7. Results 3: Modelling the inclination towards a dwarf spheroidal galaxy can give biased results.

We here examine the case of an additional unknown inclination angle. We place our mock galaxy at an inclination angle of 60° towards the observer and set the inclination as a free parameter in our models.

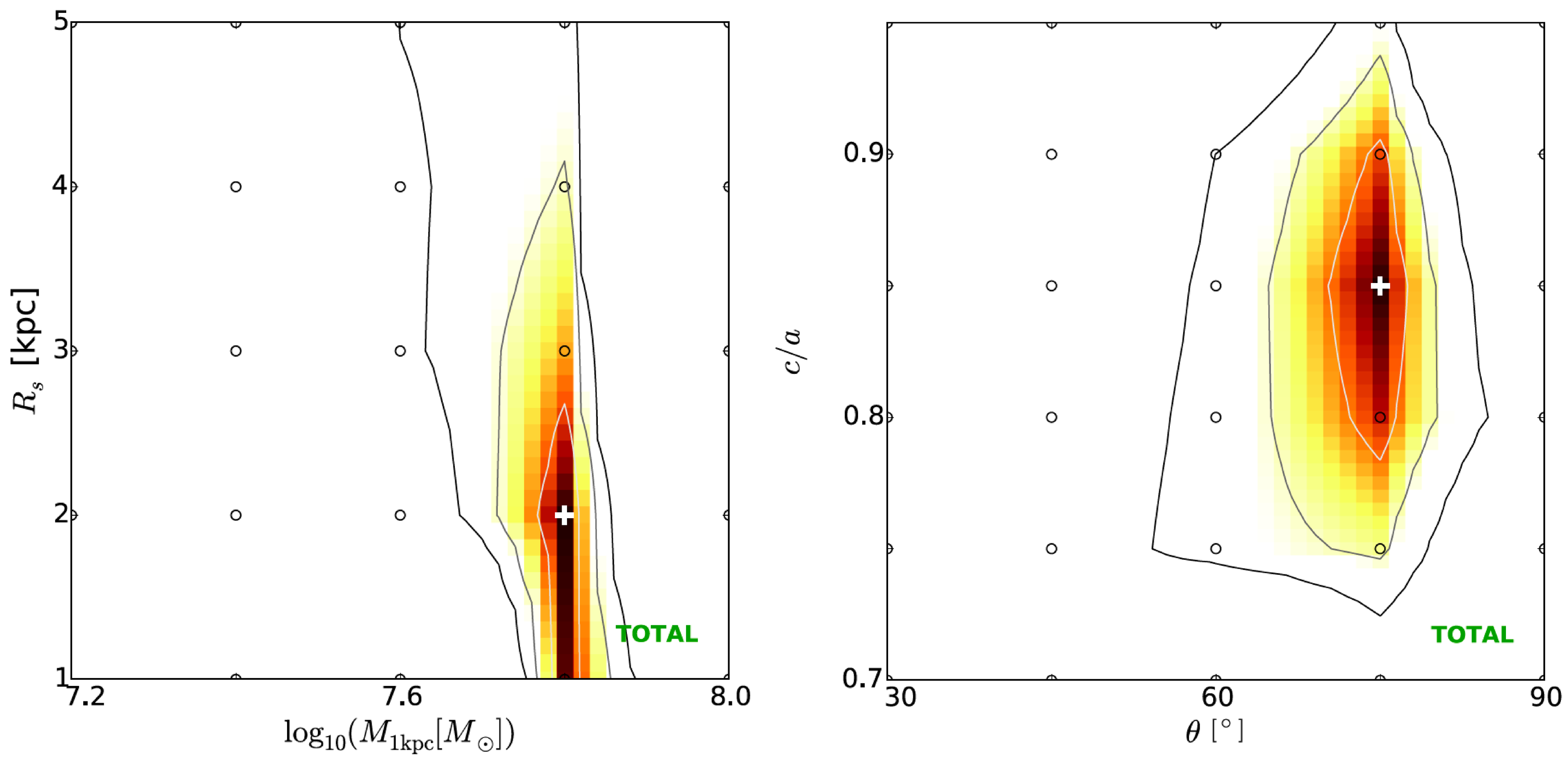

Figure 5: Probability contours after fitting our inclined mock data consisting of 10^4 stars.
Left: The mass and scale radius are recovered.
Right: Though close, the correct inclination angle is not recovered within our 2σ-confidence intervals. The flattening parameter is consequently shifted to slightly rounder values. Therefore, the results are biased.

Conclusion

Schwarzschild's orbit superposition method can be used to constrain the characteristic parameters of an axisymmetric dwarf spheroidal galaxy, especially if the inclination is known.

References

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