Effects of Observational Limitations on the Kinematic and Mass Modelling of NGC 45

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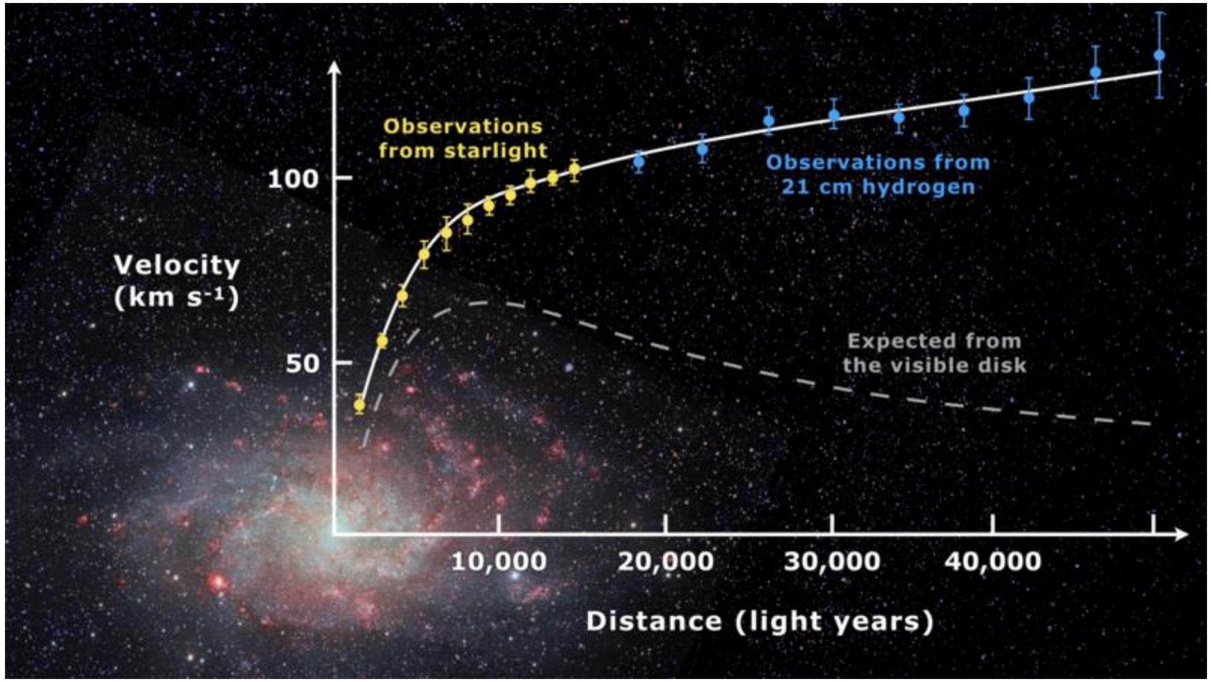
Scientific Context

- Rotation curves of galaxies provide strong evidence for the presence of DM, as they remain flat at large radii rather than declining as expected from visible matter alone
- The decomposition of rotation curves into contributions from stars, gas, and the DM
  halo is therefore essential for studying gal actic dynamics and constraining halo properties.

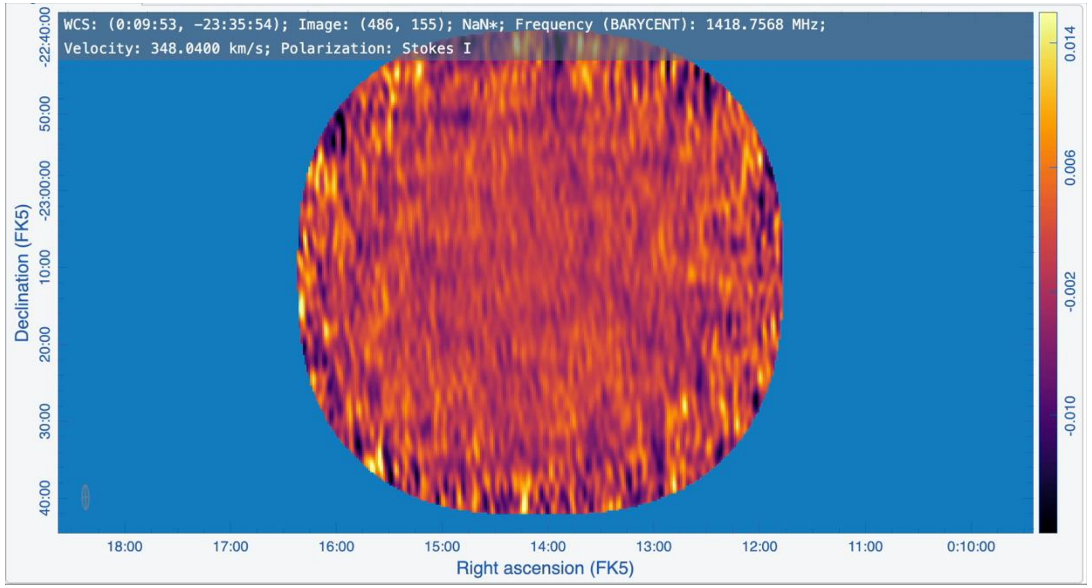
- Beyond determining the DM content, mass modelling provides key insights into galaxy formation and evolution.
- A major cosmological applications of rotation curve analysis lies in addressing the cusp-core discrepancy.



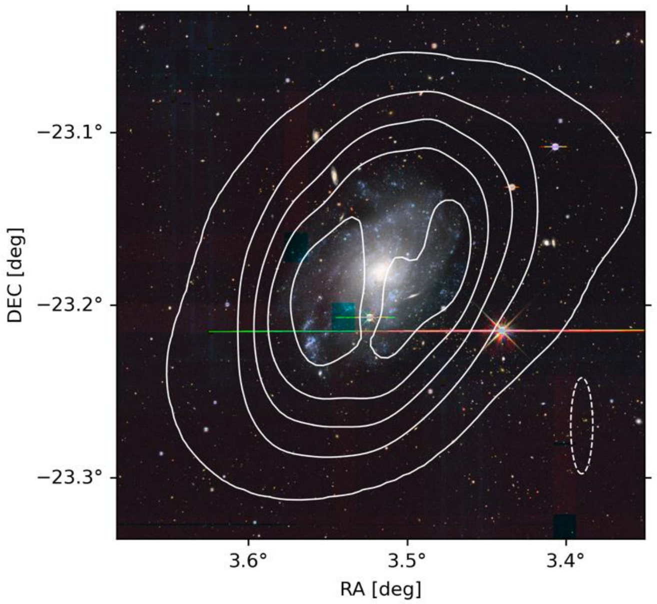
Goals of the study

- Perform kinematic and mass modelling of NGC 45.
- Compare DM halo parametrizations by modelling the galaxy with both the NFW and pseudo-isothermal profiles to evaluate how well each reproduces the observed rotation curve.
- Assess the impact of observational limitations, including sensitivity and angular resolution, on the accuracy and reliability of mass modelling results.

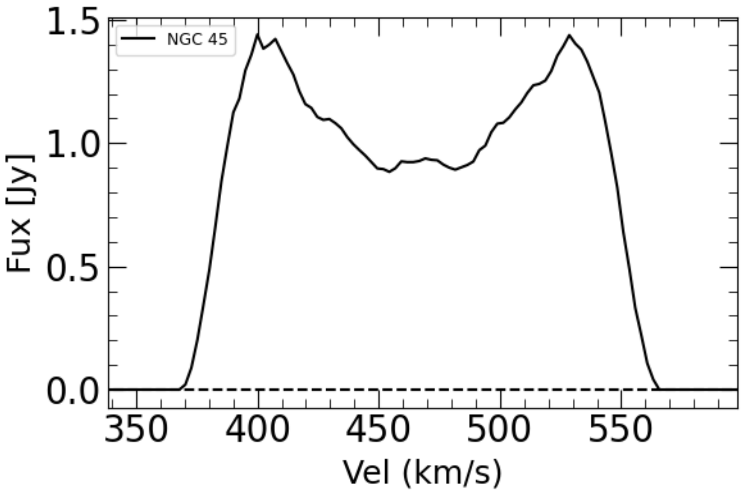
Radio Properties of NGC 45



HI data cube from ATCA observations

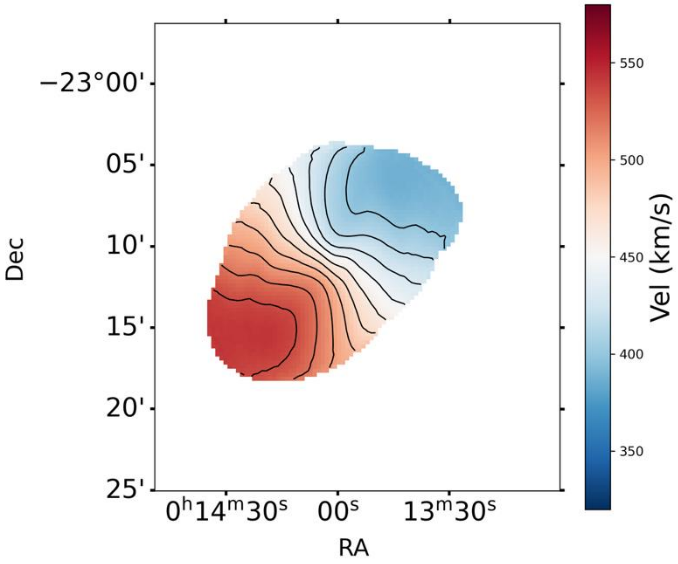


HI map overlaid on the DES optical image



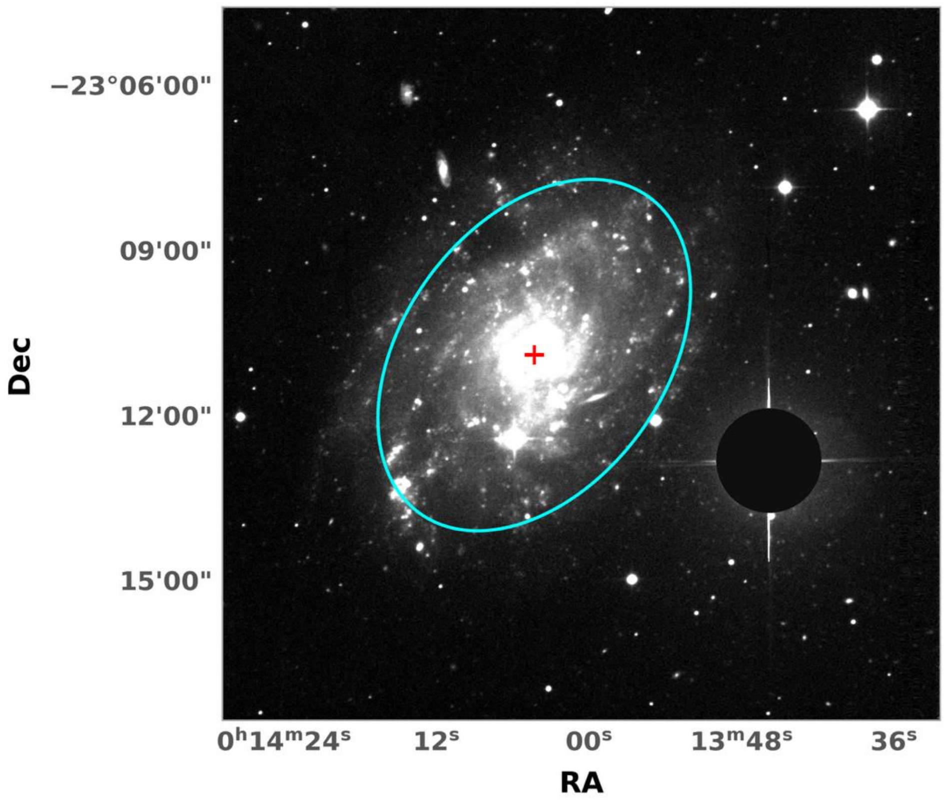
HI global profile

- Integrated flux = 192.48 ± 5.47
- Total HI mass at a distance of 6.6 Mpc = 1.97 x 10^9 M⊙
- Extension of the HI disc = 16'
- Peak HI column density = 1.06 x 10^{21} atoms/cm^2.
- V_{sys} = 466 km/s
- W_{20} = 178.4 km/s
- W_{50} = 161.4 km/s

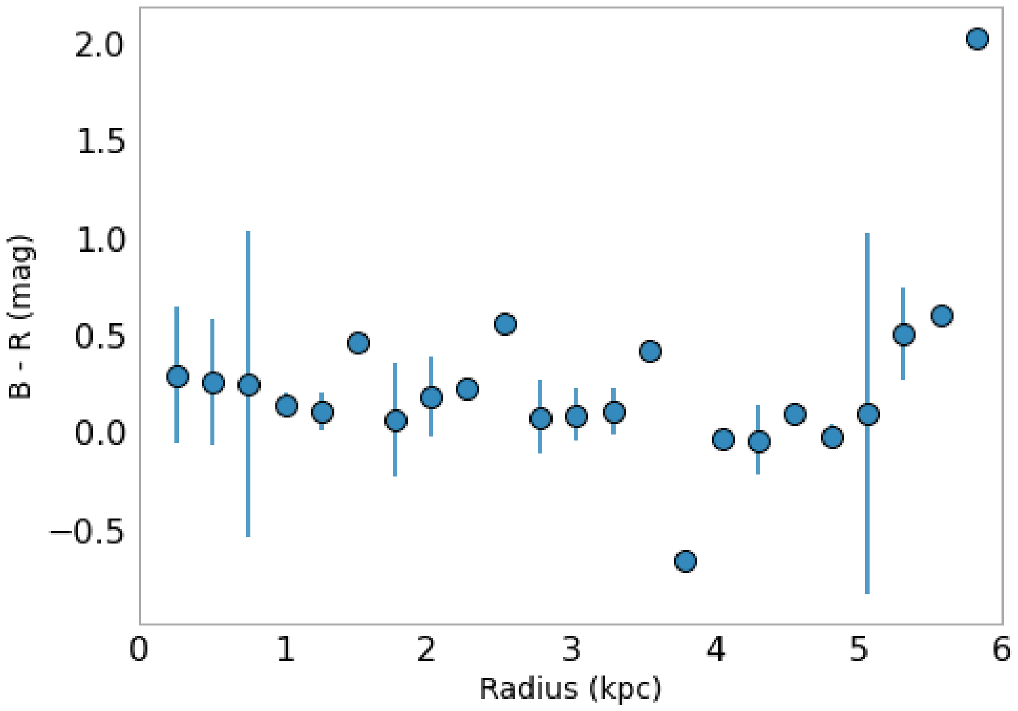


Observed velocity field

Stellar properties of NGC 45



Geometry parameters measured by isophotal fitting using photutils

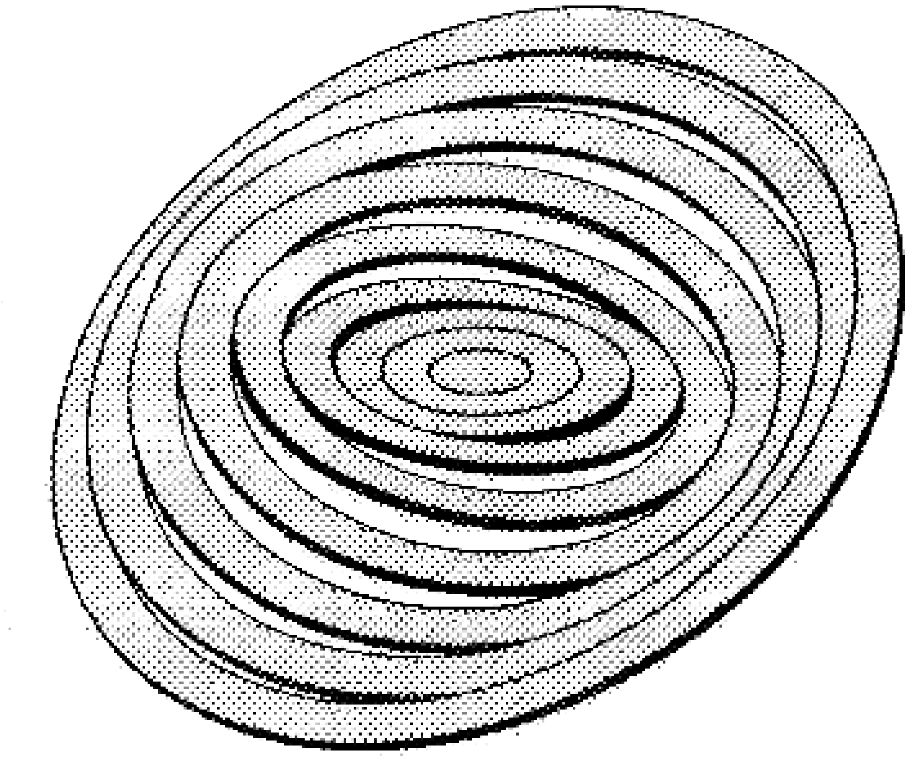


Colour profile measured by isophotal fitting using photutils

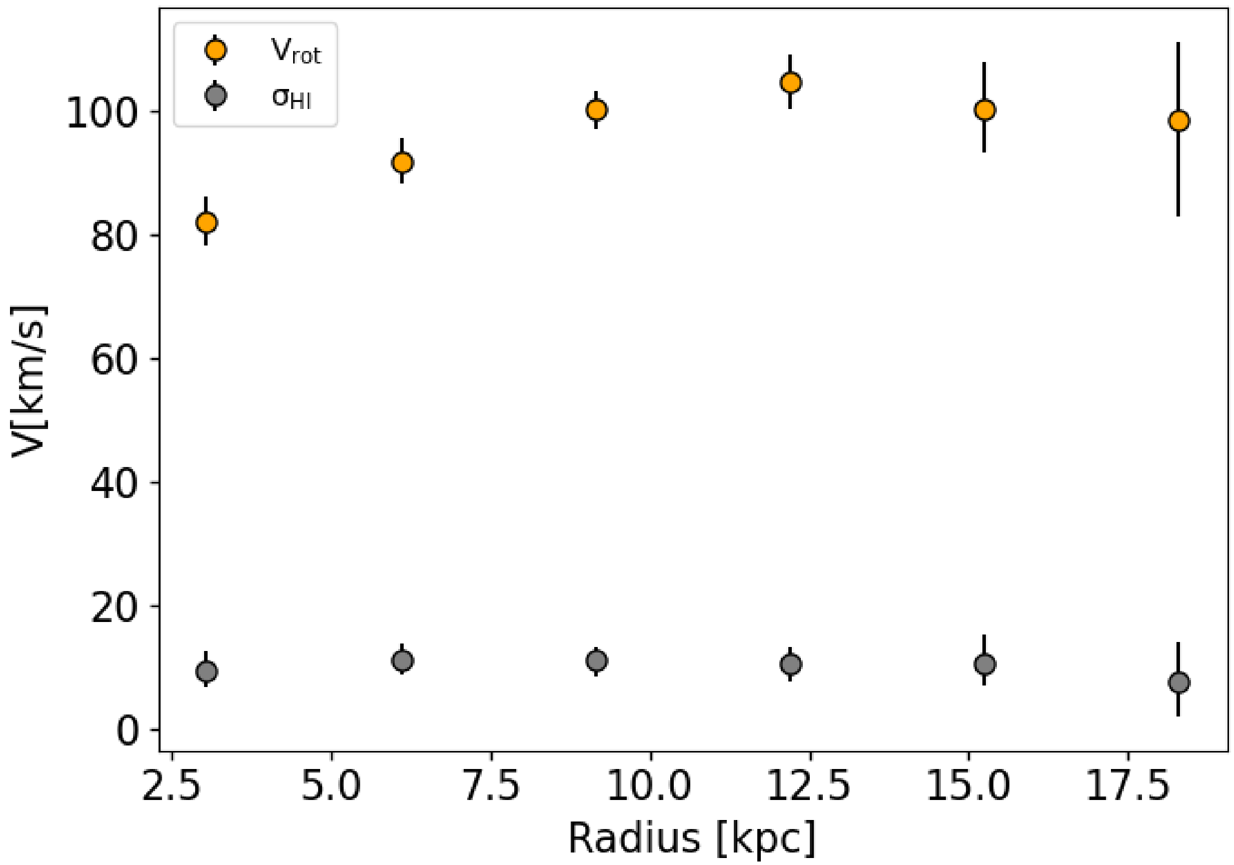
- Inclination: 50°
- Ellipticity: 0.3
- Centre: +003.5166d & -023.1820d

Kinematic Modelling

For the kinematic modelling, we perform the tilted ring model using 3D Barolo



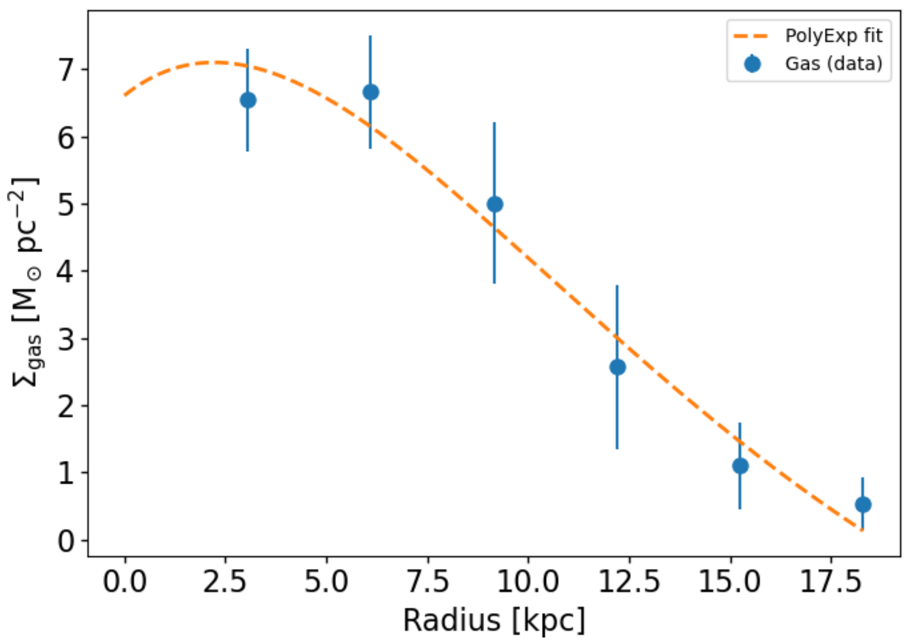
Tilted ring model



Outputs from the kinematic modelling: rotation velocity and velocity dispersion.

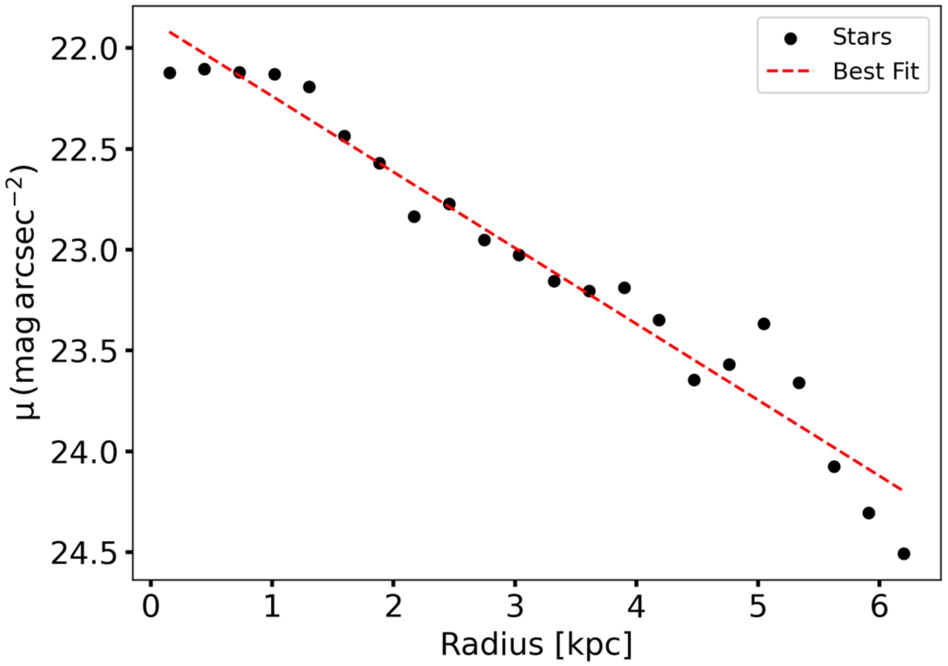
Functional forms of the gas surface mass density profile and stellar surface brightness

$$\Sigma_{gas} = \Sigma_0 e^{-R/R_d}(1 + c_1 R + c_2 R^2 + \ldots c_n R^n)$$



Σ_0 = 6.6 $M_\odot$/pc^2, R_d = 12.39 kpc, c_1 =1.899 and c_2 = -1.7

$$I(R) = I_e \exp\left(-b_n\left[\left(\frac{R}{R_e}\right)^{1/n} - 1\right]\right)$$



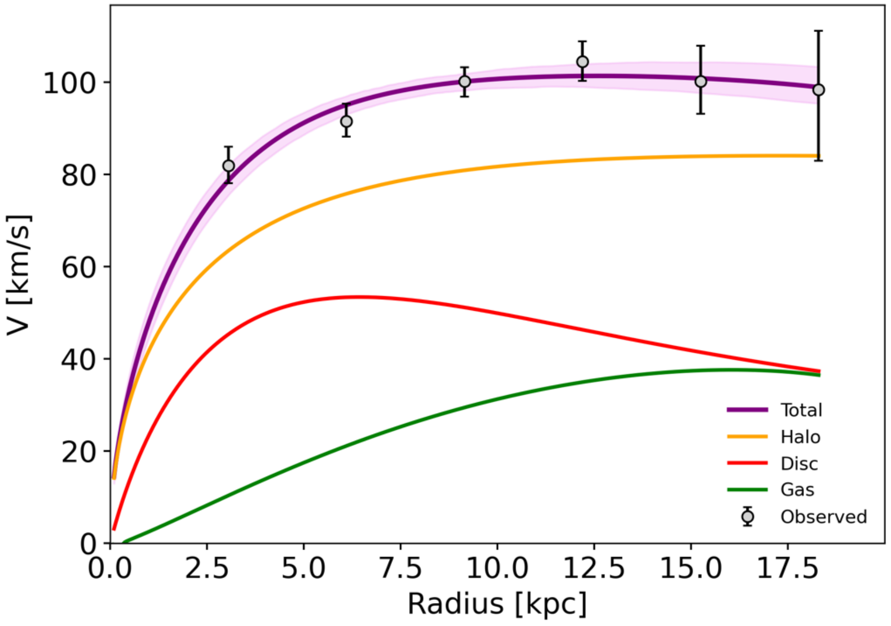
μ_e = 23.68 mag arcsec^{-2} and R_e = 4.84 kpc

Mass modelling: comparing two different parametrizations

$$V_c^2 = V_*^2 + V_{gas}^2 + V_{DM}^2$$

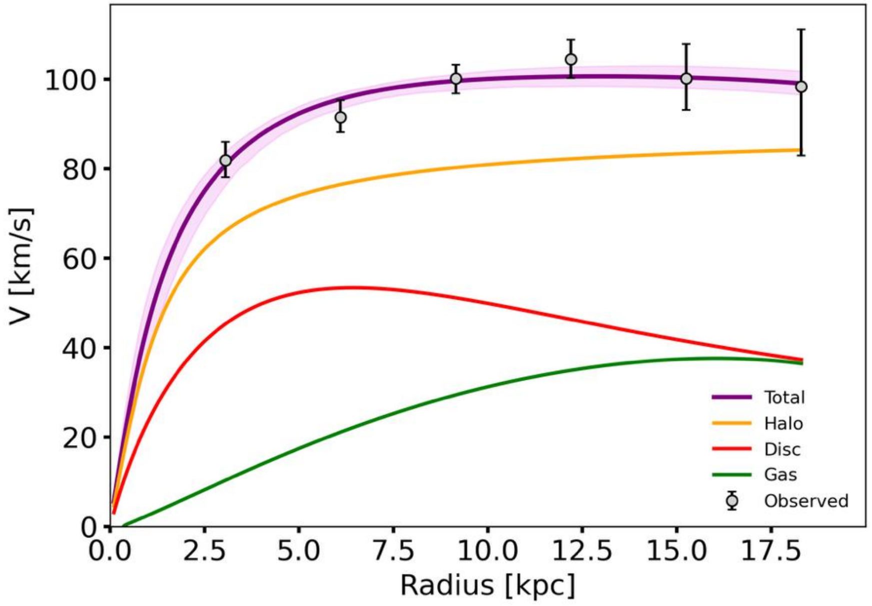
NFW model

$$\rho_{\rm NFW}(r) = \frac{4\rho_s}{(r/r_s)(1+r/r_s)^2}$$



ISO model

$$\rho_{\rm ISO}(R) = \rho_0 \left[1 + \left(\frac{R}{R_c} \right)^2 \right]^{-1}$$

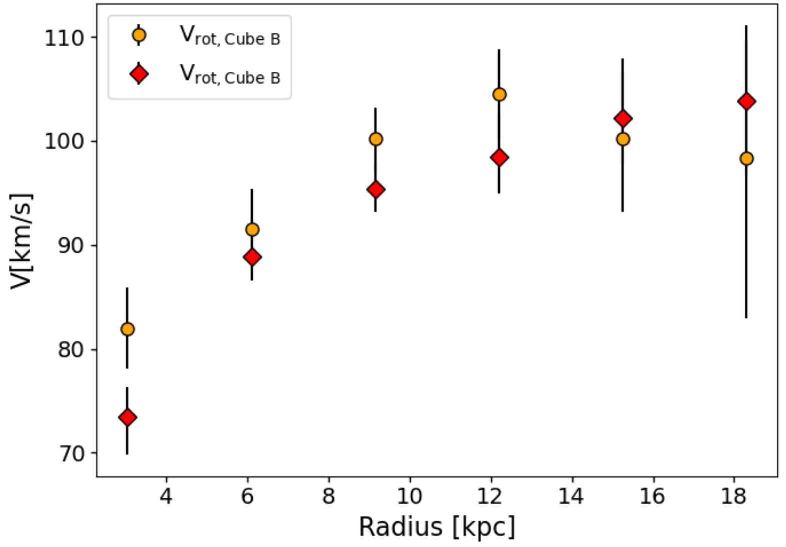


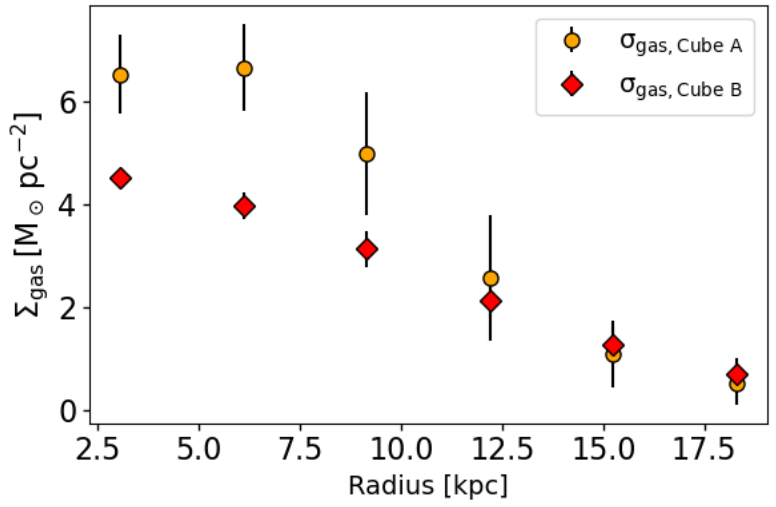
Resolution and sensitivity effects on mass modelling

Summary of the 4 HI data cubes used to assess the effects of spatial resolution and S/N on the kinematic and mass modelling results of NGC 45

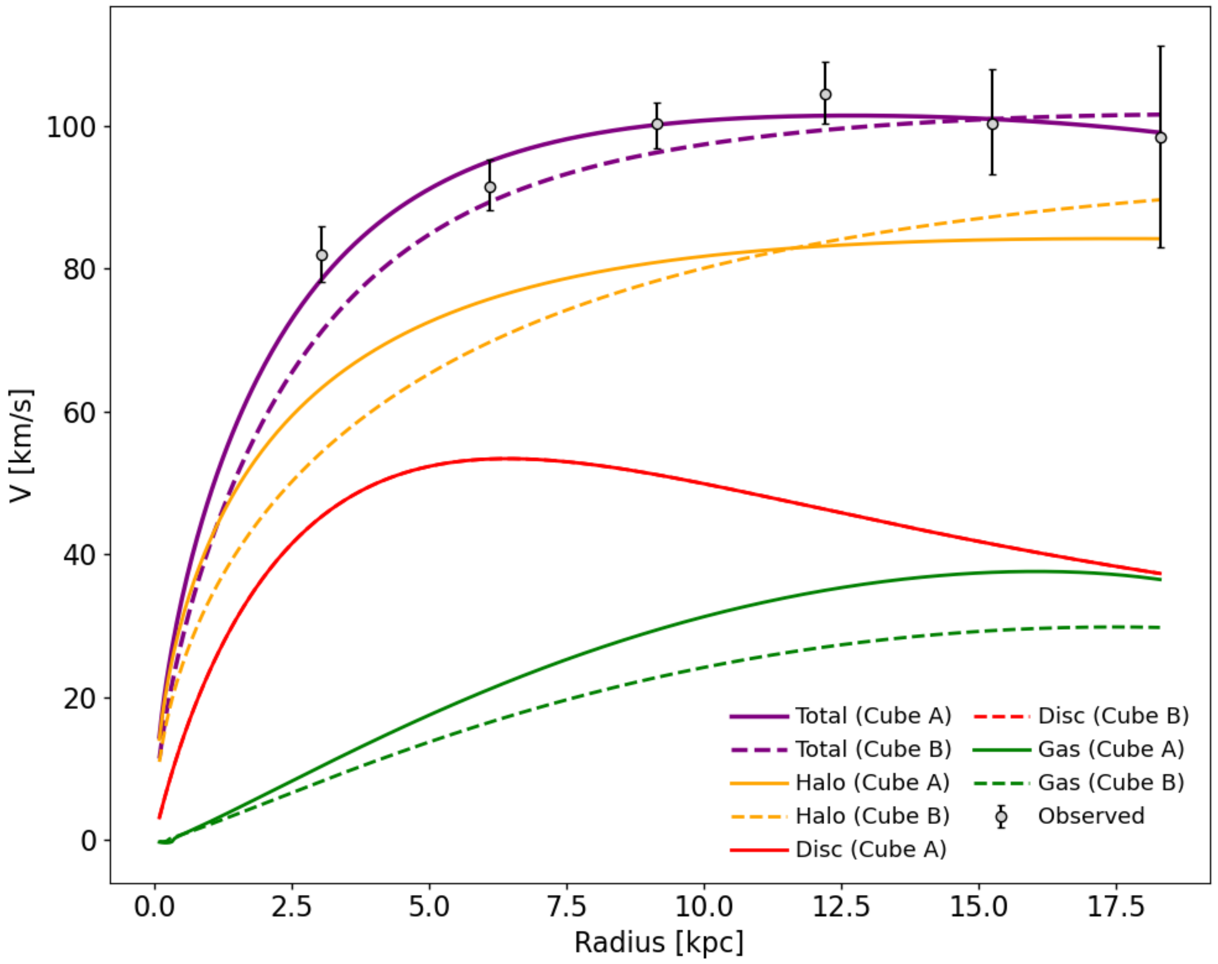
Cube	Beam size	Beams across disc	S/N
A – Original	$191'' \times 54''$	~ 5	34
B – Spatially degraded	$320'' \times 320''$	~ 3	34
C – Noise-degraded	$191'' \times 54''$	~ 5	5
D – Combined-degraded	$320'' \times 320''$	~ 3	5

Resolution effects on mass modelling

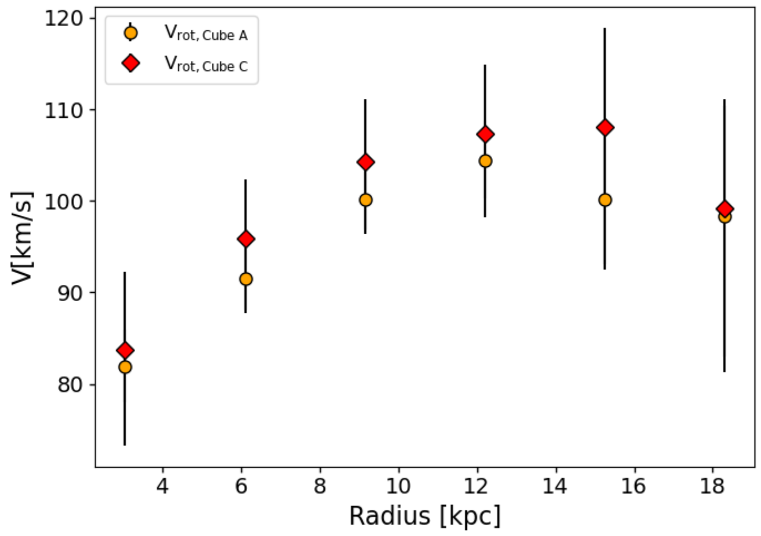


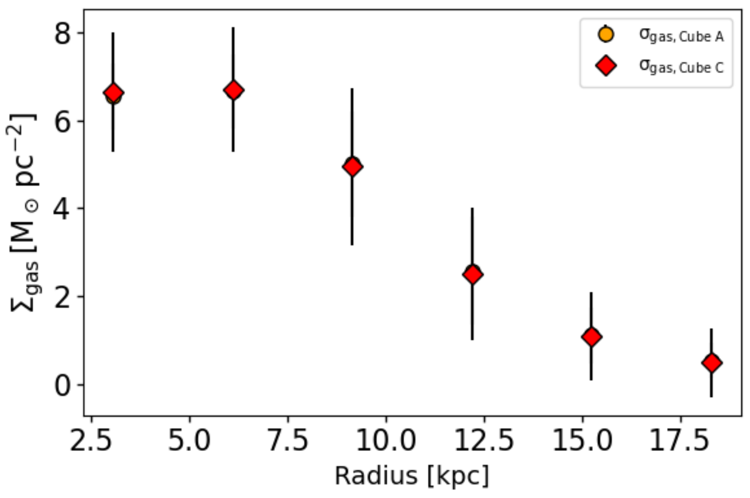


NFW model in Cube A and Cube B

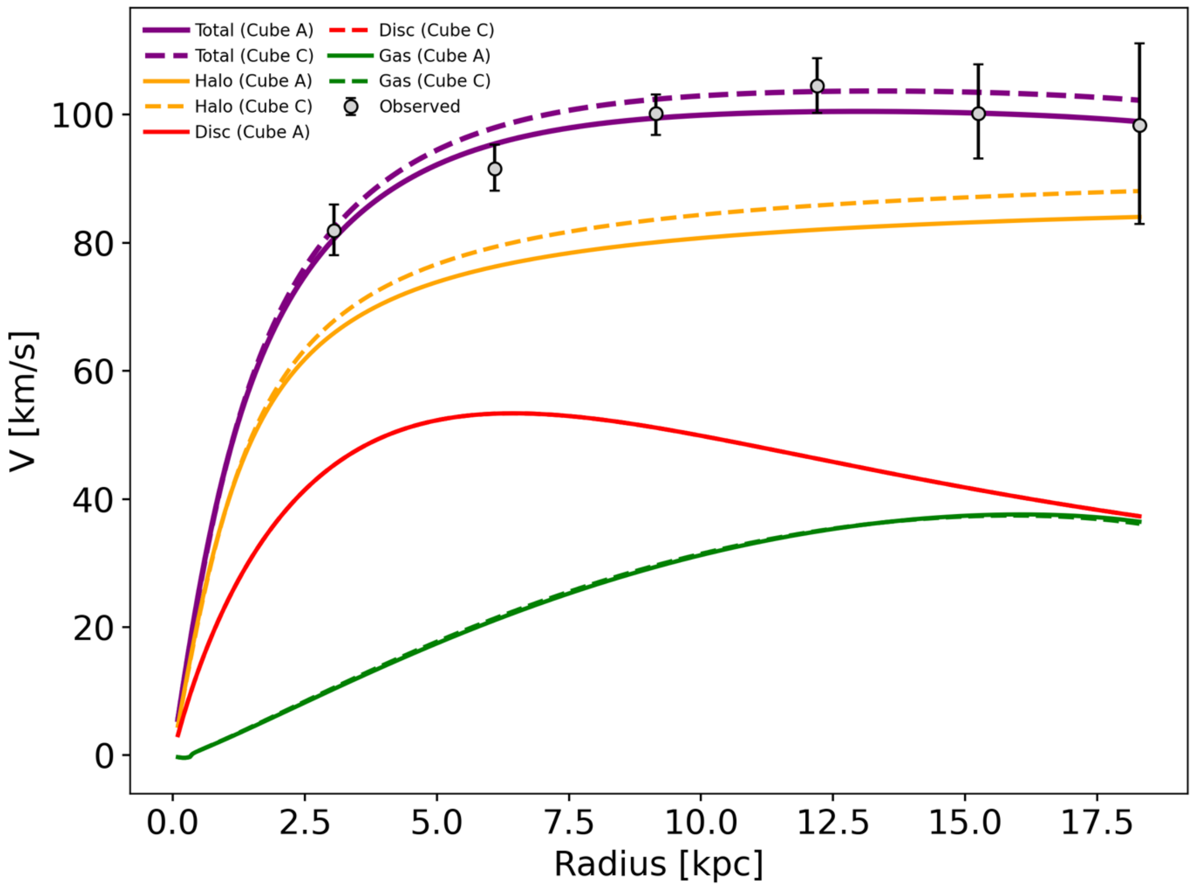


Sensitivity effects on mass modelling

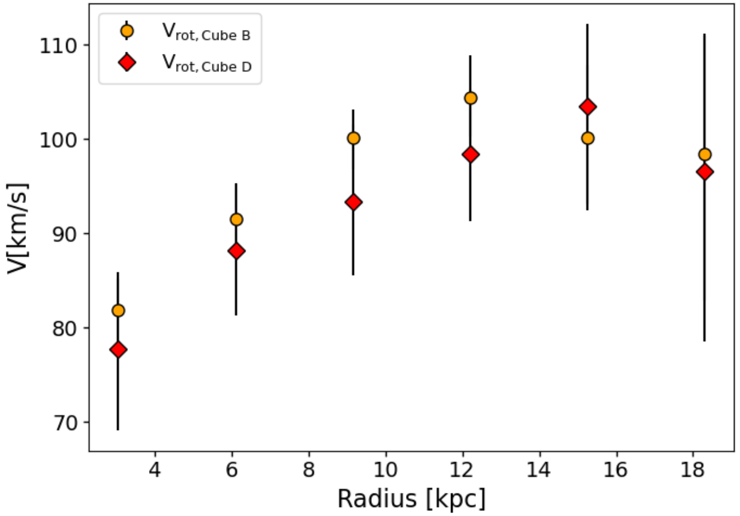


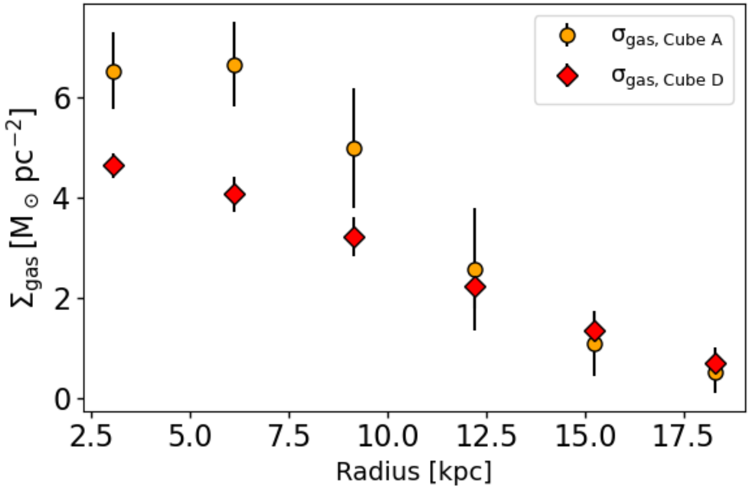


ISO model in cube A and cube C

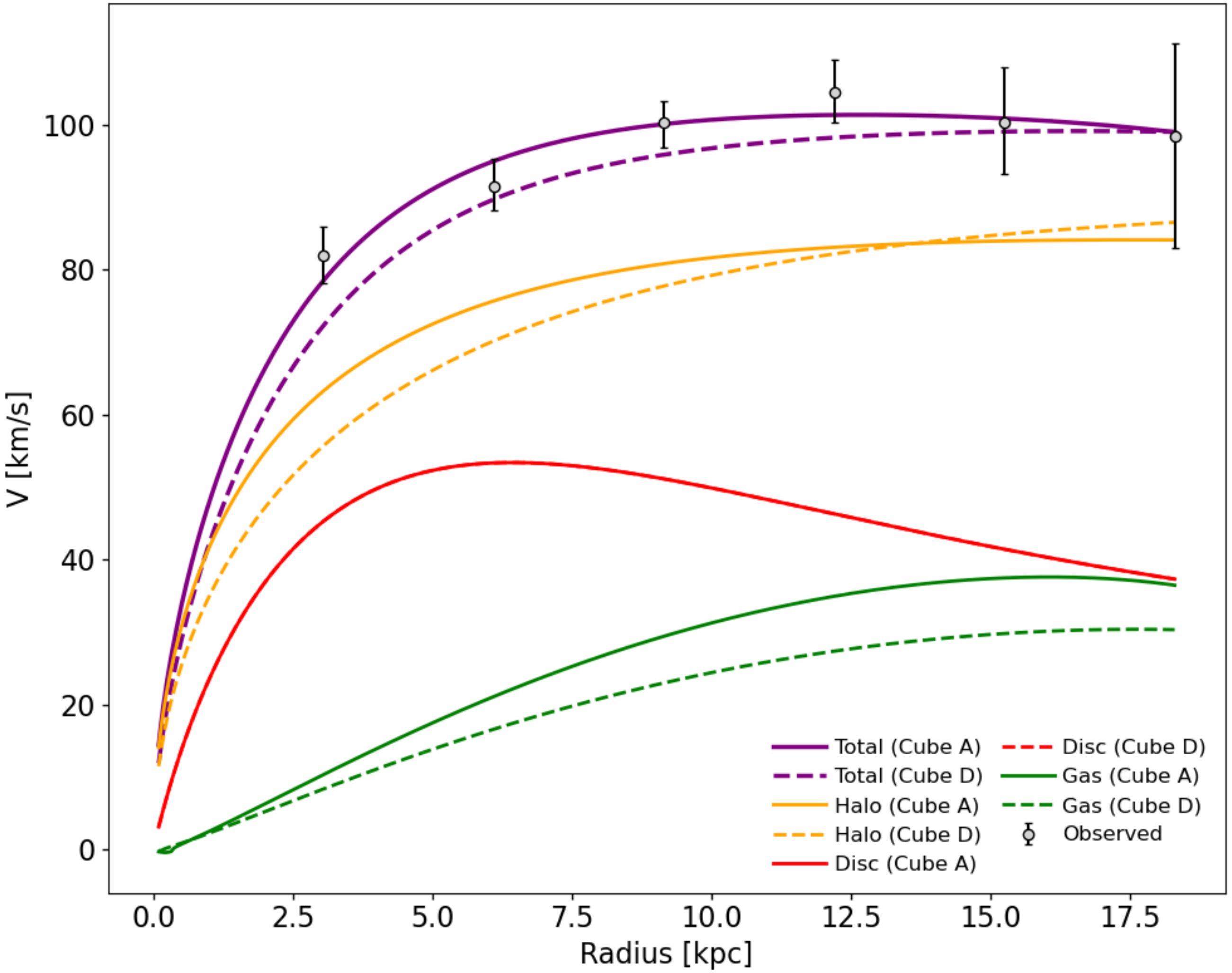


Resolution and sensitivity effects on mass modelling

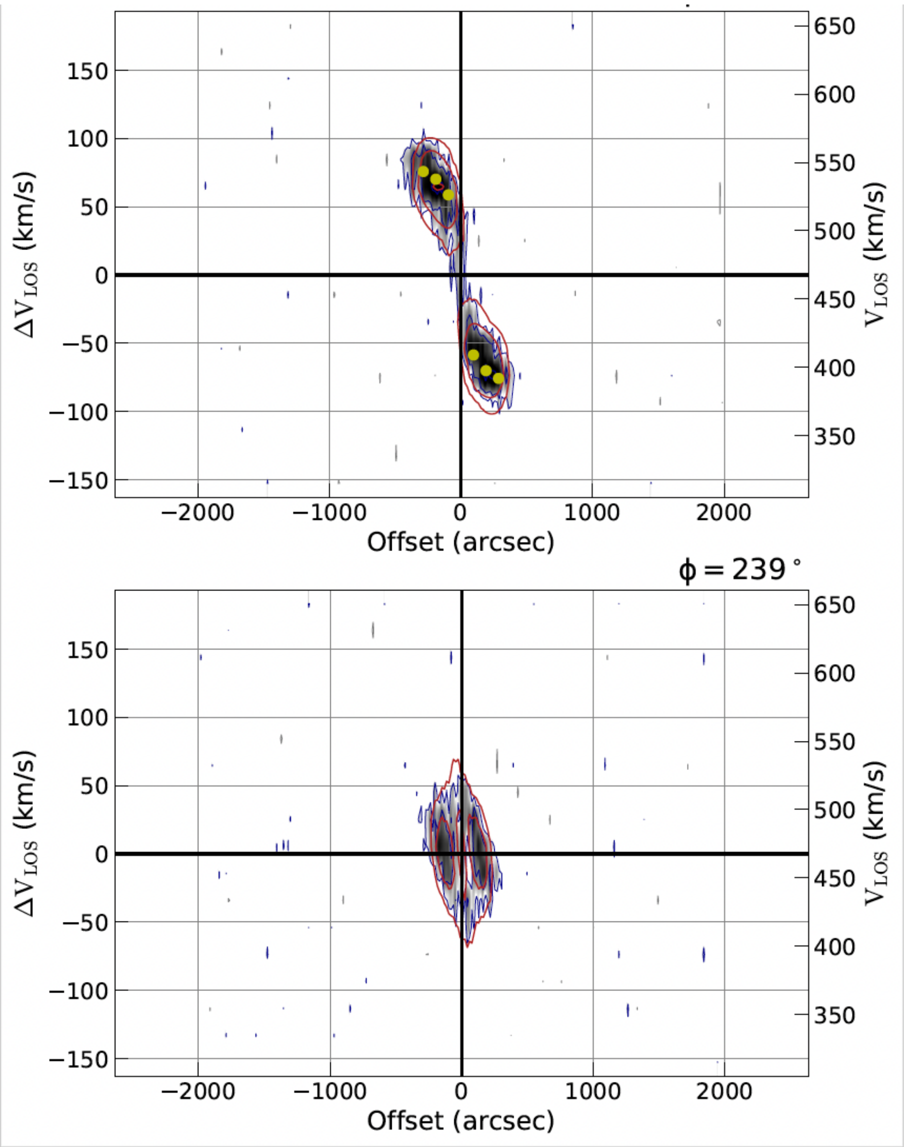


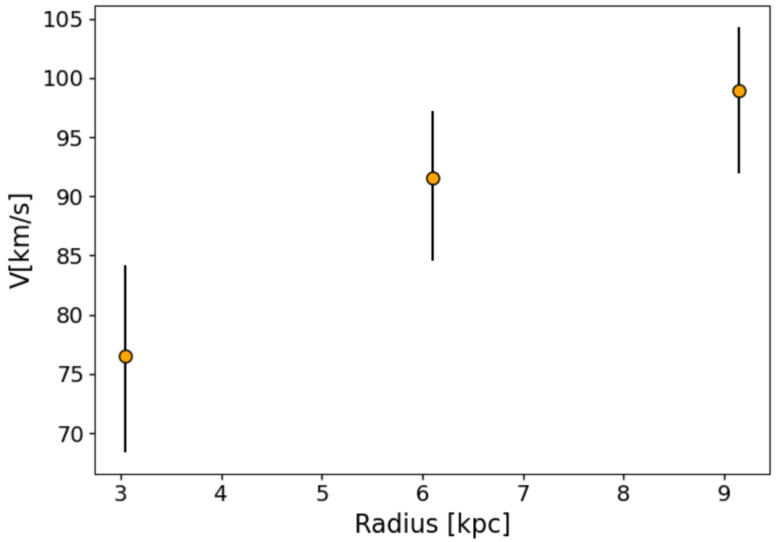


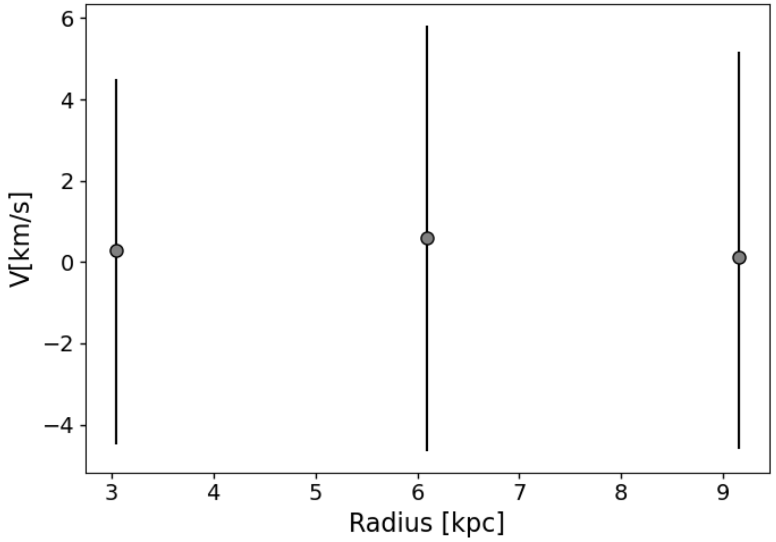
NFW model in cube A and cube D



Effects of spectral resolution on kinematic modelling







Summary

- NGC 45 is ideal for mass modelling, given its simple structure.
- The difference between the two models (NFW and ISO) is not significant, given the data quality and spatial coverage.
- When the galaxy is resolved 3 beams across the galactic disc, the rotation velocity is lowered, the inner slope is flattened and central emission is redistributed towards large radii, producing a flatter and more extended surface mass density profile.
- When the galaxy has lower sensitivity, the change in the rotation velocity is modest and the surface mass density profile is almost unaffected.
- When the resolution and sensitivity are poor, the quality of the fit severely deteriorates.
- The NFW and the ISO exhibit the same qualitative response to the effects of angular resolution and sensitivity, where parameters shift towards denser and more compact halo.

Next steps

- Extend the NGC 45 work to well resolved galaxies located in different environments and with different morphological complexities.

1. **Sample definition from SPARC**
   - Use SPARC as baseline sample.
   - Apply selection cuts: $30° < i < 75°$ and exclude Im / BCD / dwarf galaxies.
   - Focus on regular, rotationally-supported disc galaxies.

2. **Crossmatching with HI surveys**
   - Identify galaxies with available HI data cubes by crossmatching with: THINGS, HALOGAS and WHISP
   - Build a cube-available sub-sample with well-defined beam and noise properties

3. **Simulate high-redshift observations**
   - Redshift galaxies to z ≈ 0.03–0.06 (MeerKAT regime) and z ≈ 0.3–0.4 (SKA regime), degrading spatial resolution, sensitivity, and spectral resolution to match MeerKAT and SKA-Mid, ensuring ≥3 beams across the HI disc.

4. **Assess kinematic and mass-model biases**

Complementary plots