Using HI Gas to Model Dark Matter Haloes in MaNGA

University of St Andrews
UKRI Science and Technology Facilities Council

Stephanie Campbell (They/Them),
Anne-Marie Weijmans, Karen Masters, David Stark

Galaxies Exist in Dark Matter Haloes

- The stuff that we can see in a galaxy (stars, gas, dust, etc) only inhabits the very central regions of an extended halo of dark matter [Figure 1]
- We can use dynamical models to measure how much dark matter is present, and how it is distributed

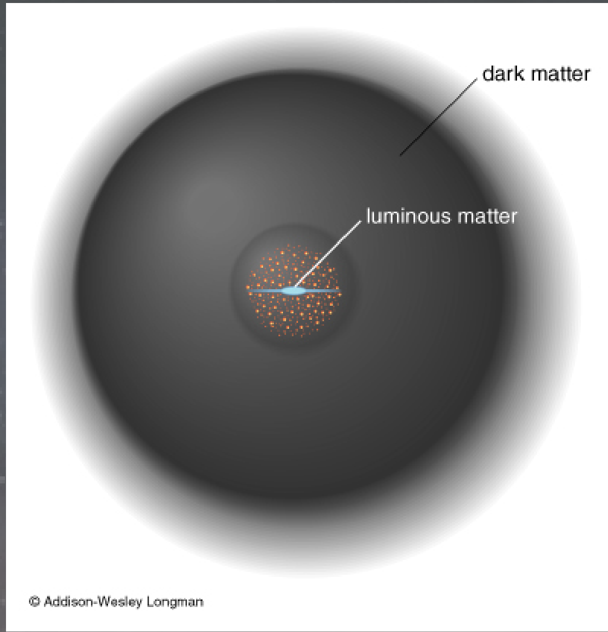
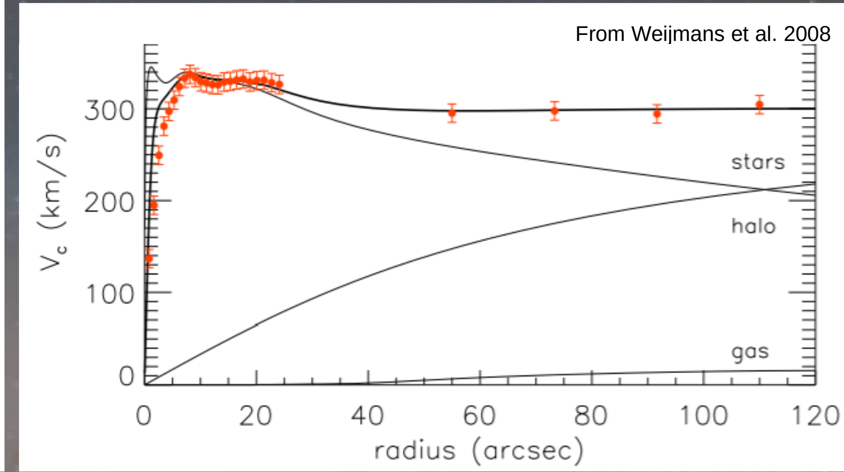


Figure 1 (Left): The luminous matter is only in the very centre of the extended dark halo

Figure 2 (Below): Circular velocity components of NGC 2974, showing need for halo to match observations



What Do Dynamical Models Do?

- Predict the motions we'd expect in the stars based on a chosen mass distribution
- Integral Field Spectroscopy measures actual motions
- We approximate the luminous mass distribution, and then add in different dark matter distributions until we best fit the observations [Figure 3]

Luminous potential

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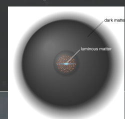
Dark potential



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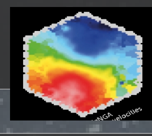
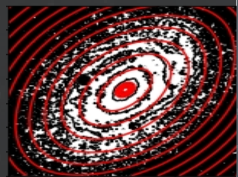
Observed motions



Use images to approximate the surface brightness and convert to mass



→ Model →

Integral field spectroscopy measures spectra at each pixel, giving stellar kinematic maps

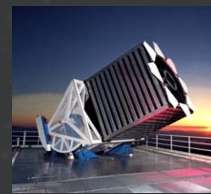


Figure 3 (Above): Schematic showing the combined luminous and dark potentials dictate the observed motions, and indicating how models can be used to predict the observations and find best fit haloes

In this project we use the JAM method of Jeans modelling, developed by Cappellari (2008)

How Would We Like to Improve Them?

- IFS Surveys only probe stellar kinematics which don't reach into the outer regions where dark matter is most dominant
- Cold neutral Hydrogen extends out into these parts, and can be observed using 21cm radio observations [Figure 4]

Figure 4 (Left): NGC 6946 observed in the optical on the left (Digitized Sky Survey), and in HI on the right (WSRT), on the same scale (from Boomsma et al. 2008)

Single Dish Data vs Array Data

- Full radio array observations let us measure spatially resolved HI gas kinematics maps [Figure 5] but we only have this for a handful of galaxies
- We can observe many more galaxies using single radio dish observations, but these give no spatial information, just one spectrum [Figure 6]
- HI-MaNGA (Stark et al. 2021) is observing thousands of galaxies using the Greenbank Telescope

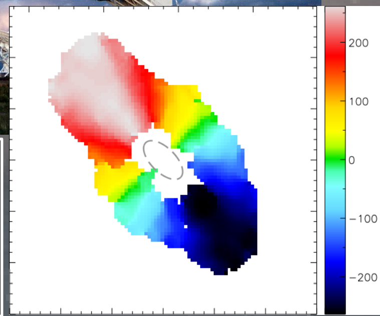
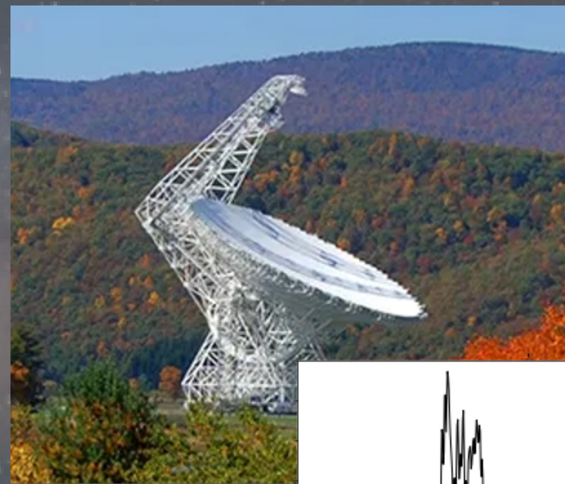


Figure 5: the VLA telescope (NRAO), and inset is a spatially resolved velocity map for NGC 2974 (Yang et al. 2020)



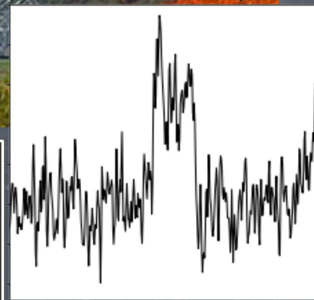
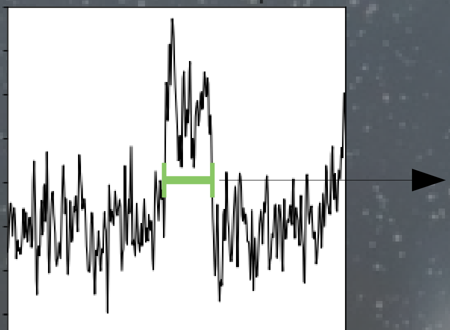


Figure 6 : The GBT dish, and inset is a 21cm radio spectrum from HI-MaNGA



- Measuring this width gives an indication of the circular velocity of gas rotating within the beam, which acts as one extra data point to constrain the model at large radii (where dark matter is most dominant)

Creating a JAM Model with No Dark Matter

- Figure 7 shows the circular velocity for our best fit model, with no dark matter and no knowledge of the HI measurement
- Inset is the observed (left) and predicted (right) root mean squared velocity (V_{RMS}), it is a good fit
- Note that the projected velocity fits the data we have in the centre well, but lacks any information beyond the cyan line (the end of our mass model), and so does NOT match the HI data

Adding Dark Matter

- Adding dark matter to the model, but not adding HI to the likelihood leaves too few constraints on the outer regions
- Many different haloes can fit the inner data but can take many forms in the outer regions

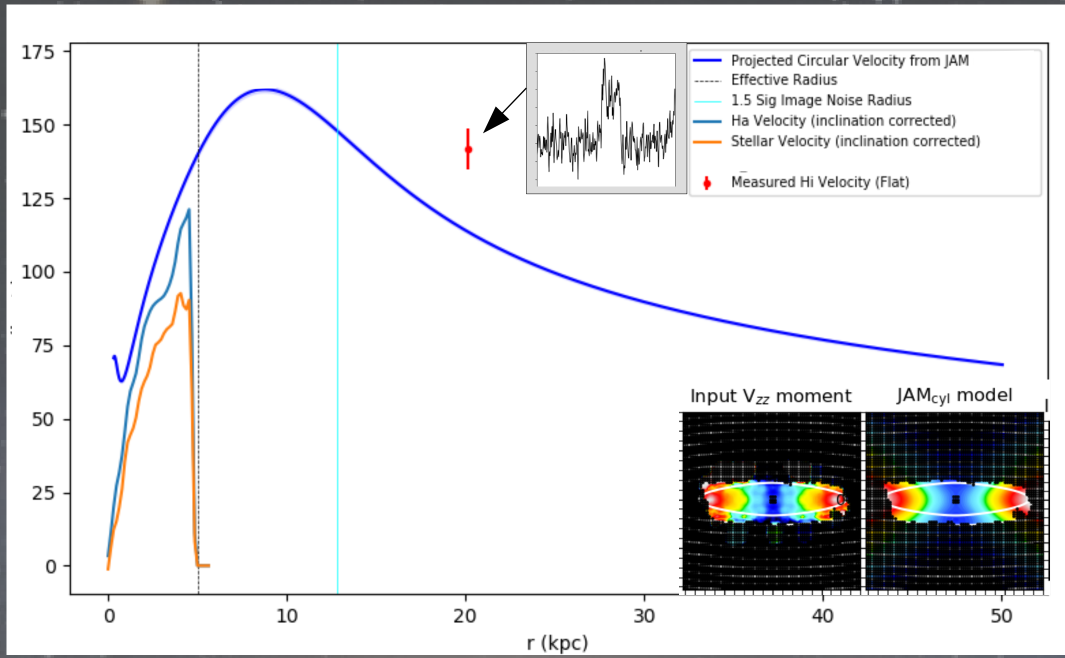
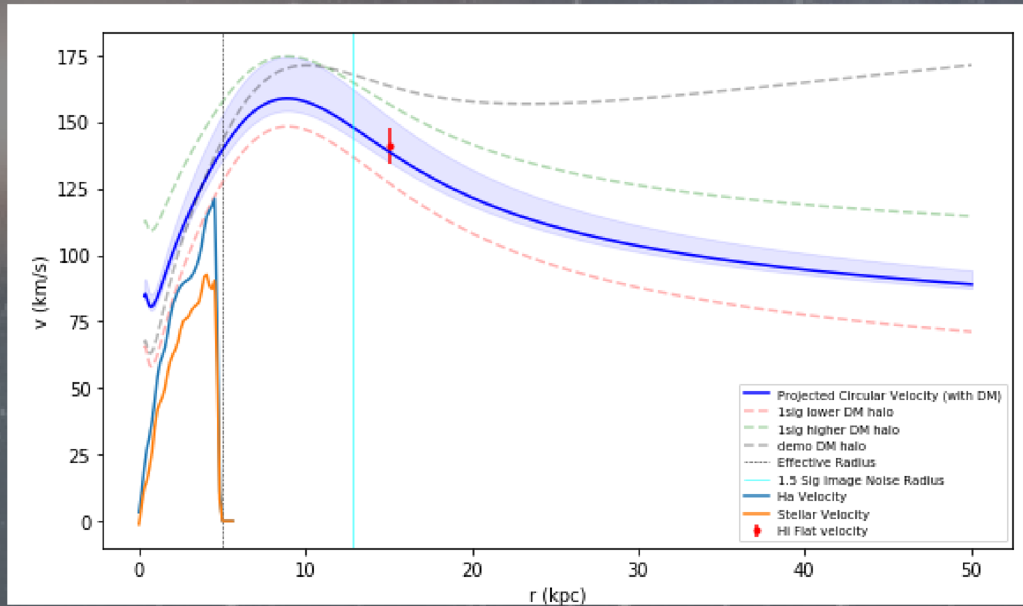


Figure 7: Rotation curve for an example galaxy, for a model with no dark matter and using only IFS data (the HI data is not included in the likelihood). The Hα and Stellar velocities come from MaNGA, as does the V_{RMS} map displayed in the inset

Figure 8: Creating a model with a dark matter halo included, but without including the HI data in the likelihood leaves too much freedom in the outer regions



We need the HI constraint to tell the model what to do in the most dark matter dominant regions

In Summary

- Incorporating HI data into dynamical models could offer tighter constraints from more dark matter dominant regions
- Using spatially resolved data limits the number of galaxies we can achieve this for
- Single dish data is more readily available for a statistically significant sample of galaxies (such as in the HI-MaNGA survey)
- We need to incorporate the kinematic information from this data into the model in order to constrain the outer regions of the halo
- Single dish data lacks the spatial information, but we hope exploring the process in comparison to resolved data will allow us to use this method to probe dark matter haloes for a large sample of galaxies

Future Work

- To better determine the effects of the HI spatial uncertainty, and discern if the single dish data has enough information, we will access resolved data from the Apertif survey (using the Westerbork Synthesis Radio Telescope [Figure 9]) for comparison
- This will allow us to pull back the curtain on which regions the single dish measurements are probing, and aid in developing a robust method for adding the unresolved information

Figure 9: The WSRT is an array, so offers resolved kinematic observations of galaxies, some of which are shared with the MaNGA survey

Contact Me:

Stephanie Campbell
(They/Them)
University of St Andrews
sc381@st-andrews.ac.uk