International Centre for Radio Astronomy Research

Extended Tully-Fisher relations using HI stacking

Scott Meyer, Martin Meyer, Danail Obreschkow, Lister Staveley-Smith

Curtin University

The Government of Western Australia

The University of Western Australia

Summary

Intro

- TFR
- Where traditional methods fail
- HI Stacking

Calibrations and simulated data

- Analytical galaxies
- Simulated galaxies (from the S^3-SAX model)

Real data test case (HIPASS and HICAT)

- HIPASS direct detections
- Extension work to 6df / SKA and precursors

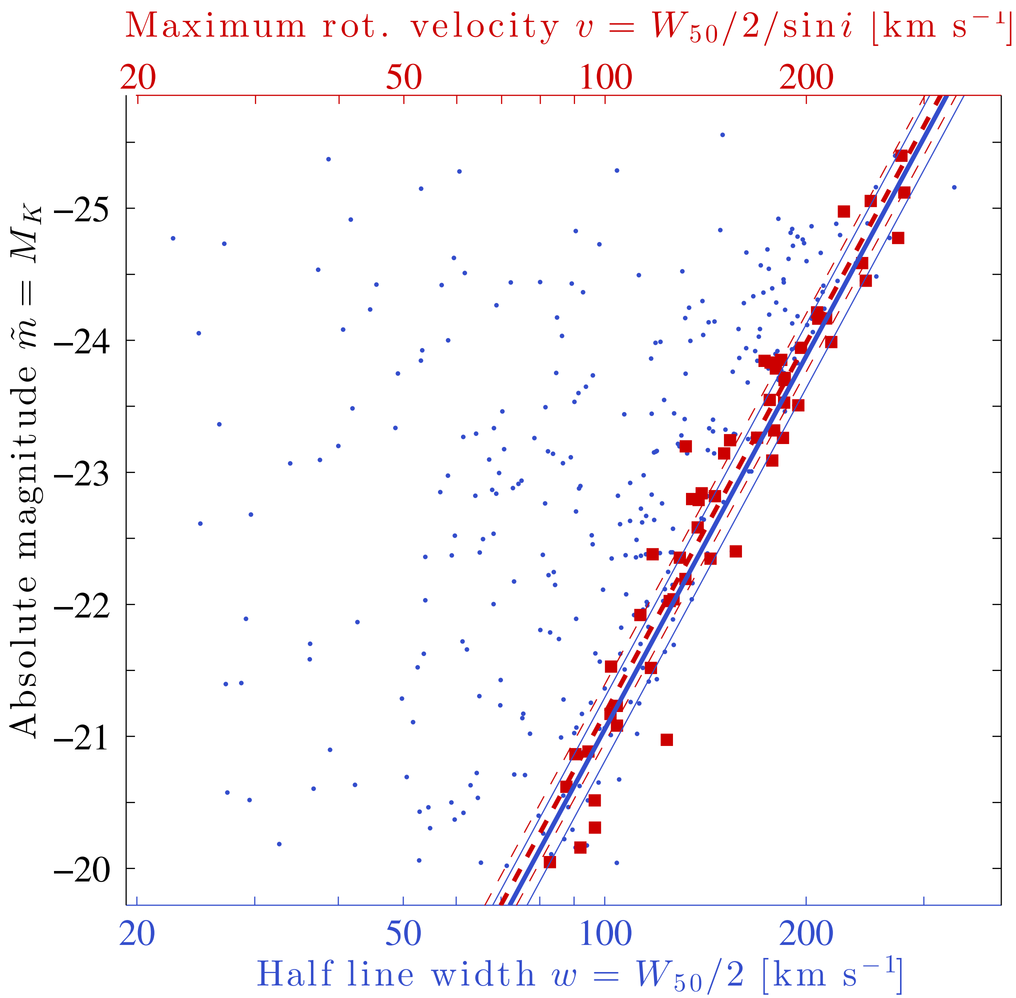
Tully-Fisher relation (TFR)

What is the TFR?

The TFR is an empirical relation between **absolute magnitude** and intrinsic HI emission line width (as a tracer of **rotation velocity**) that **spiral galaxies** follow.

What's happening here?

This particular plot demonstrates a novel way of getting TFR parameters without having galaxy inclinations (See Obreschkow & Meyer 2013 for more info)



Obreschkow & Meyer, ApJ, 2013, Vol 777, pg 140

Current limitations

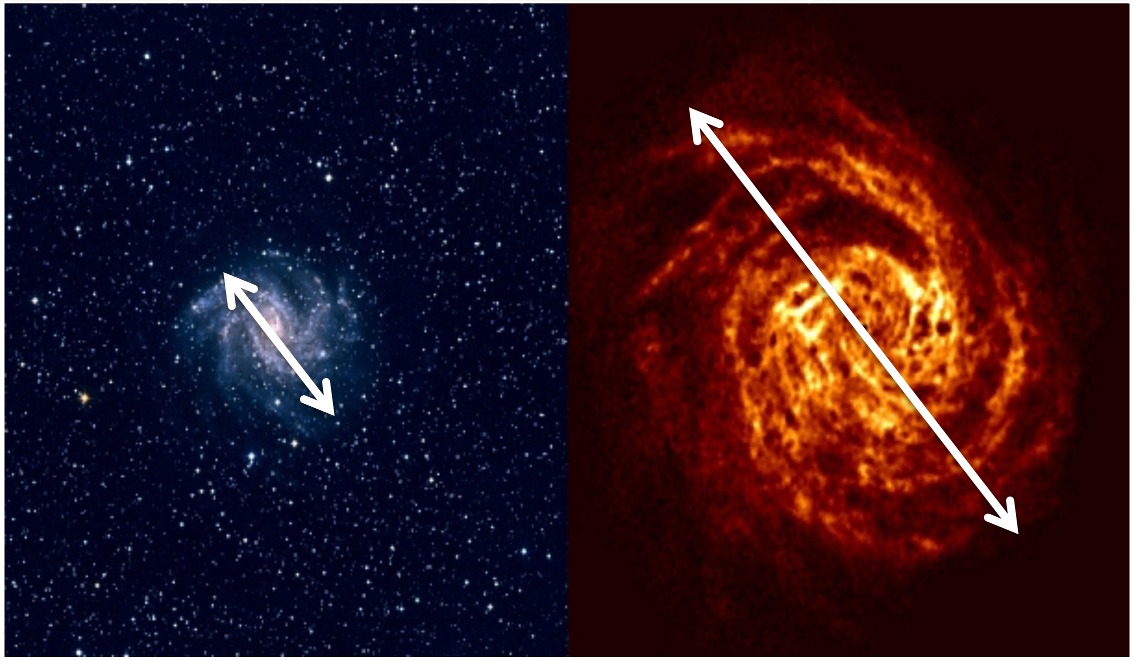
Optical vs Radio rotation measures

The TFR can be investigated in optical or radio.

Wavelength	Observed Quantity	Max Redshift	Radius Probed
Optical	Hα	Z ~ 1-1.5	low
Radio	HI	z < 0.1	High

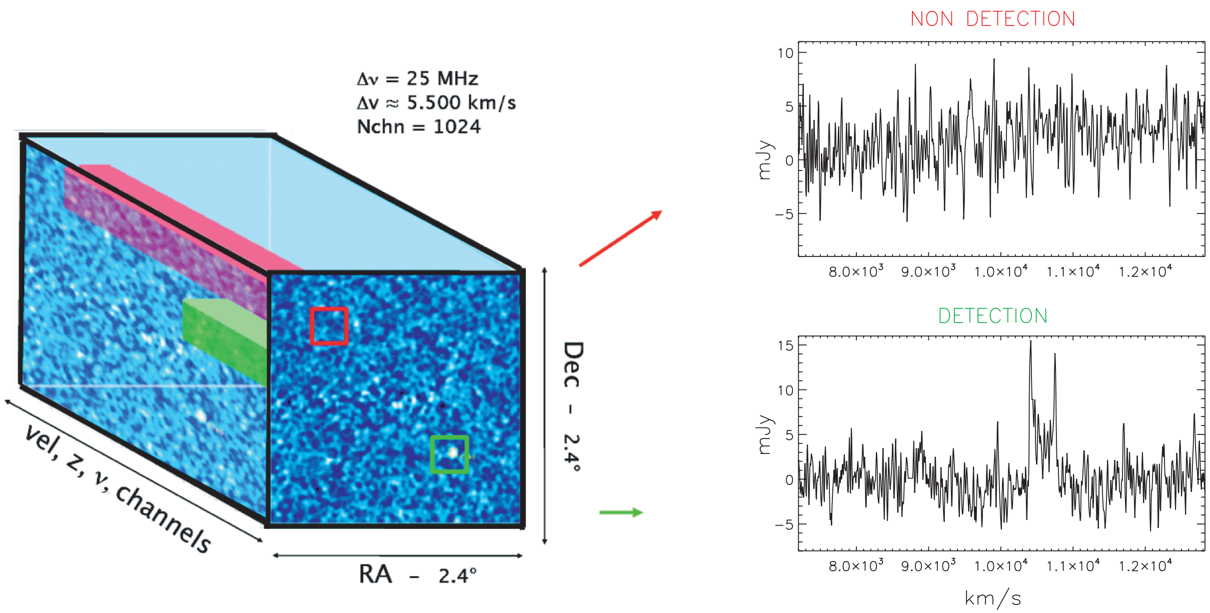
Optical probes deep, but does not necessarily retrieve the full velocity profile.

Radio probes much more of the velocity profile but is limited to z < 0.1.



NGC 6946 – left: Optical, right: Radio

HI stacking



Fabello et. al. 2011

What?

This technique seeks to creates an HI emission spectrum with increased improved signal-to-noise by combining several HI spectra (usually in an attempt to get a detection from a collection of non-detections).

How?

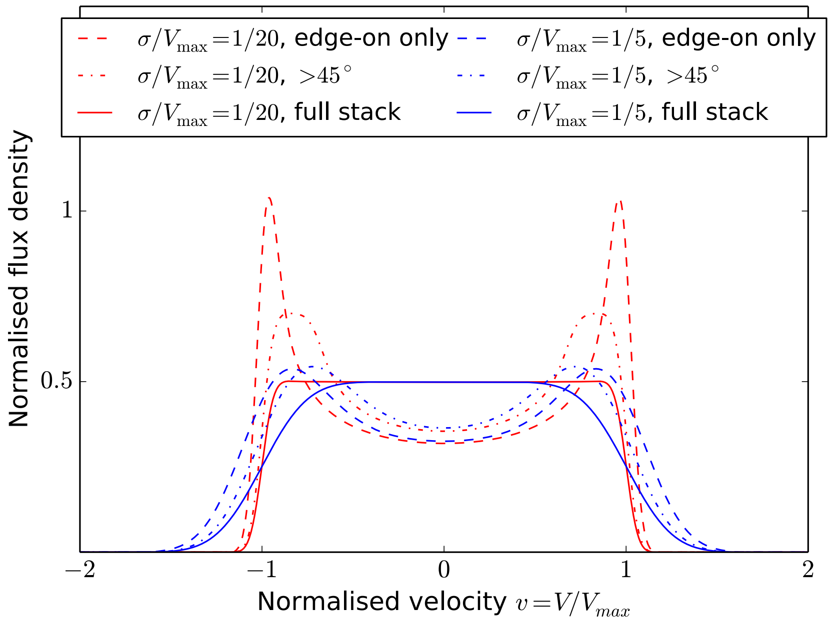
Rest-frame HI spectra from galaxies are created using optical redshift (or radio redshifts if available). These are then co-added. Signal increases proportional to N (the number of galaxies included) while noise increases as √N.

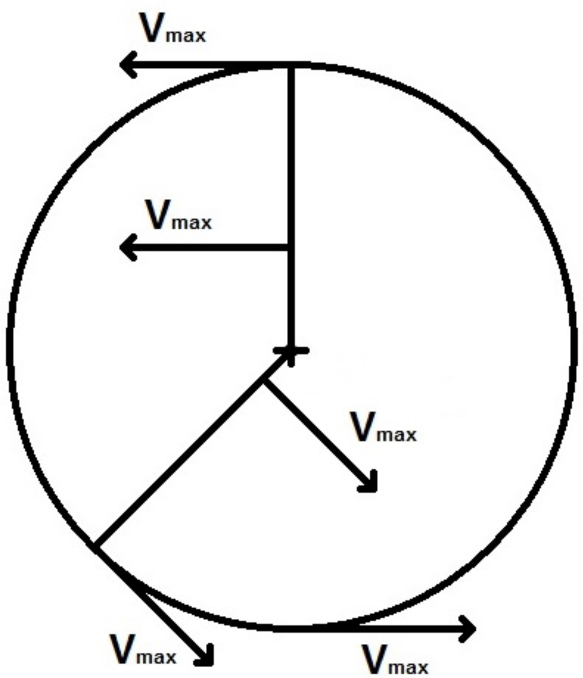
Movie at https://vimeo.com/69062721

Simulated galaxies 1

Analytically solvable galaxy profiles

A single galaxy was modeled as a disk with constant linear velocity (not constant rotation). This galaxy was projected to various different inclinations and convolved with Gaussians of varying σ/V_{max} values to simulate different random gas velocities (dispersion). Random projections of this galaxy were stacked to investigate the relation between the FWHM of the stack, and the FWHM of the deprojected galaxy.



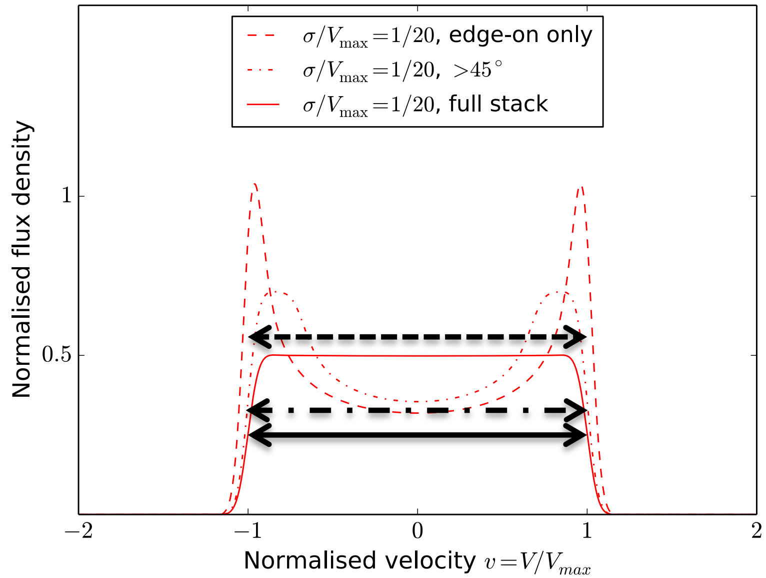


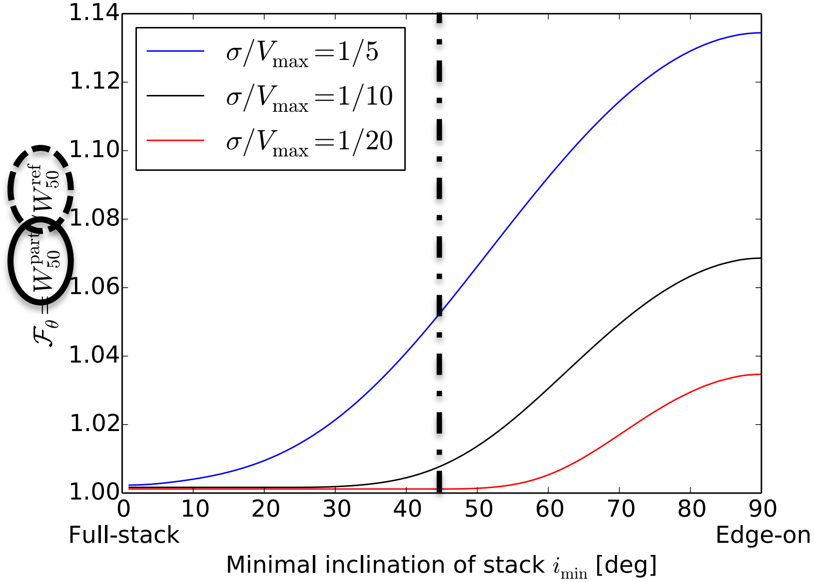
Simulated galaxies 2

Correction factor

In order to reproduce the TFR, our measured stack widths must relate in some predictable way to the deprojected widths of the input galaxies.

- $W_{50}^{\rm stack}$ = width of stacked profile
- $W_{50}^{\rm ref}$ = width of single analytical spectra, **deprojected** and **dedispersed**
- Blue = high dispersion (random gas velocities)
- Red = low dispersion





Simulated galaxies 3

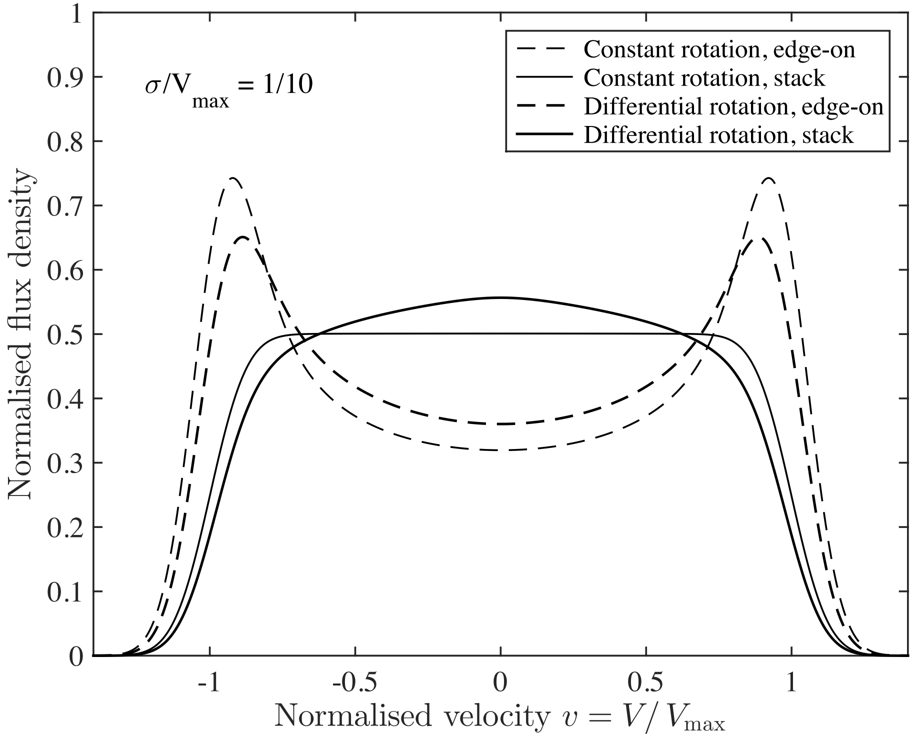
Galaxies with differential rotation

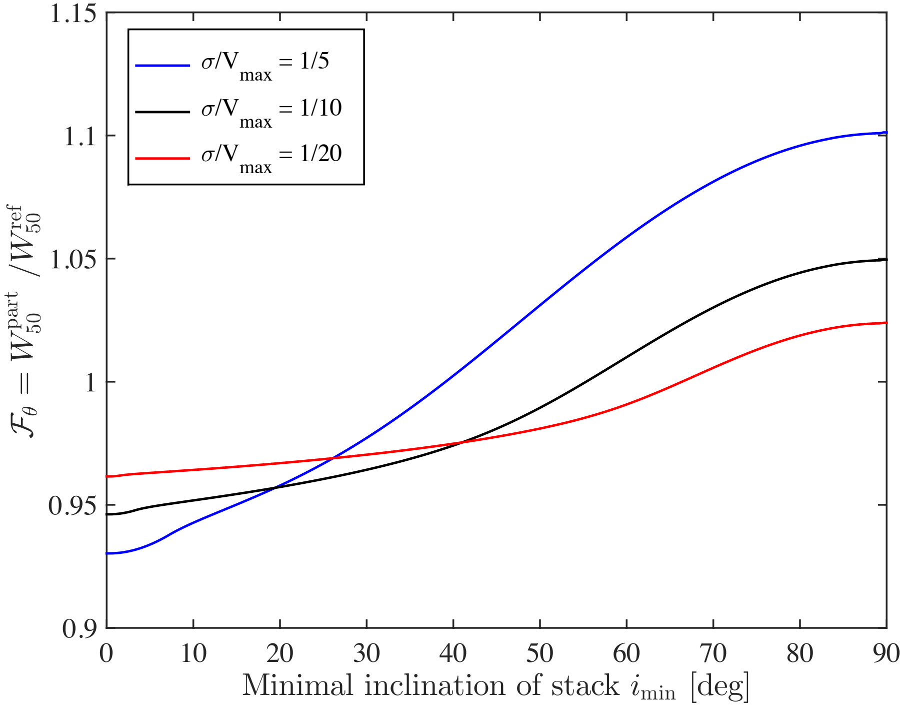
Galaxies were given an exponential rotation curve of the form:

$$V(r) = V_{\max}\left(1 - e^{-r/r_{\text{flat}}}\right)$$

Since galaxies no longer have constant velocity profiles, we prescribe a HI surface density of the form:

$$\Sigma_{\text{HI}}(r) = \frac{M_{\text{HI}}}{2\pi r_{\text{HI}}^2} e^{-r/r_{\text{HI}}}$$

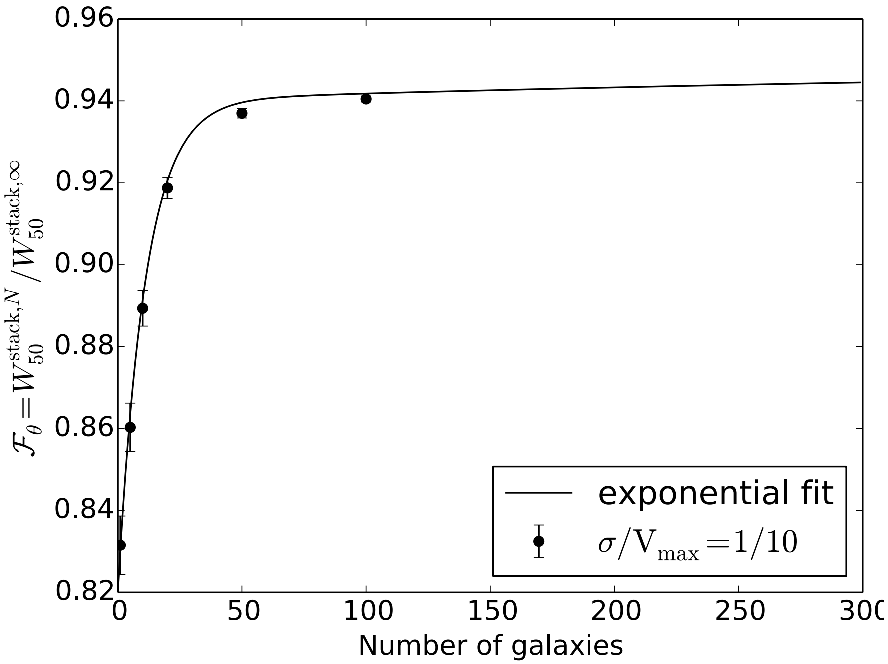


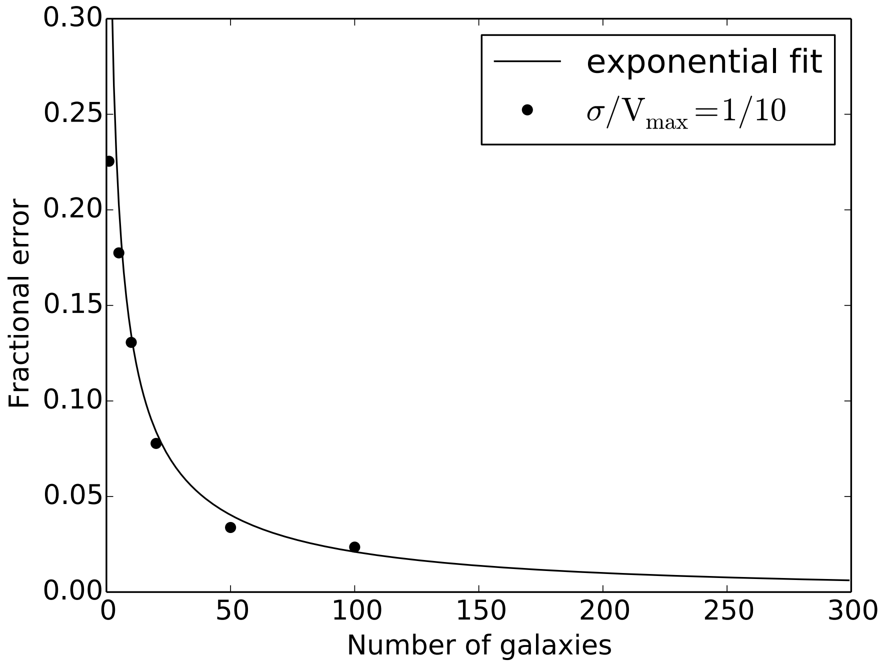


Simulated galaxies 4

Low number statistic corrections

Because galaxies enter the stack without being corrected for inclination, having a sample too small introduces an offset and scatter into $W_{50}^{\rm stack}$.



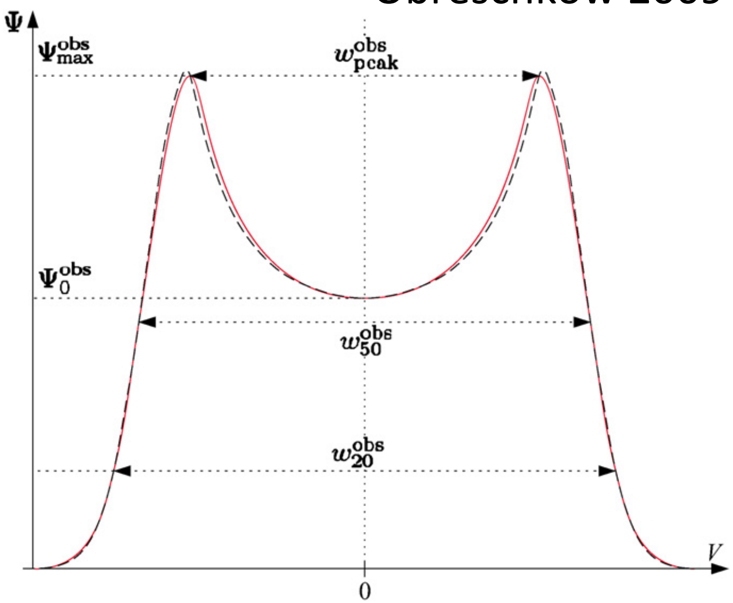


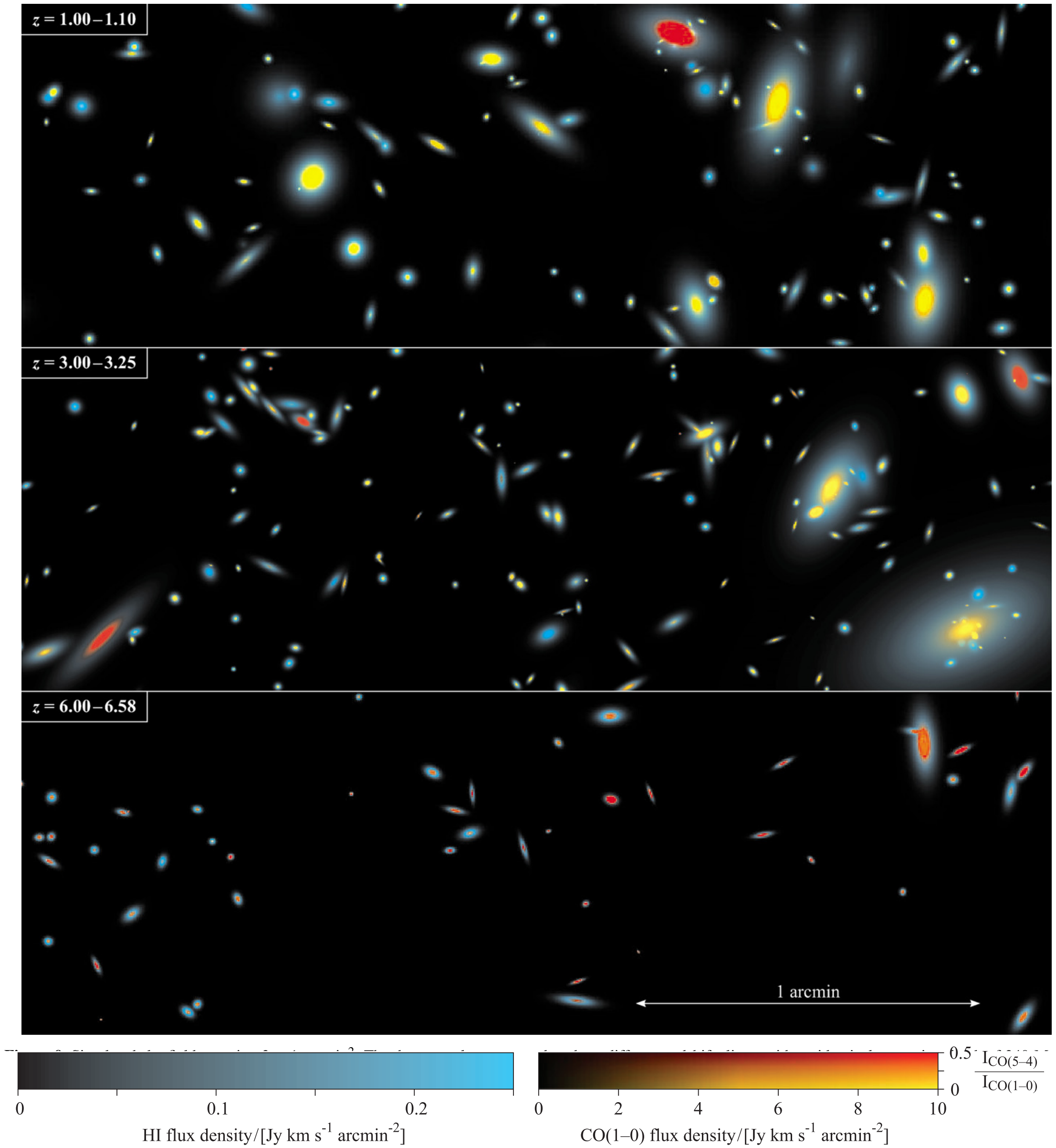
Simulated galaxies 5

S^3-SAX simulation

HI and H_2 semi-analytical model made by post-processing the Millennium simulation.

Obreschkow 2009

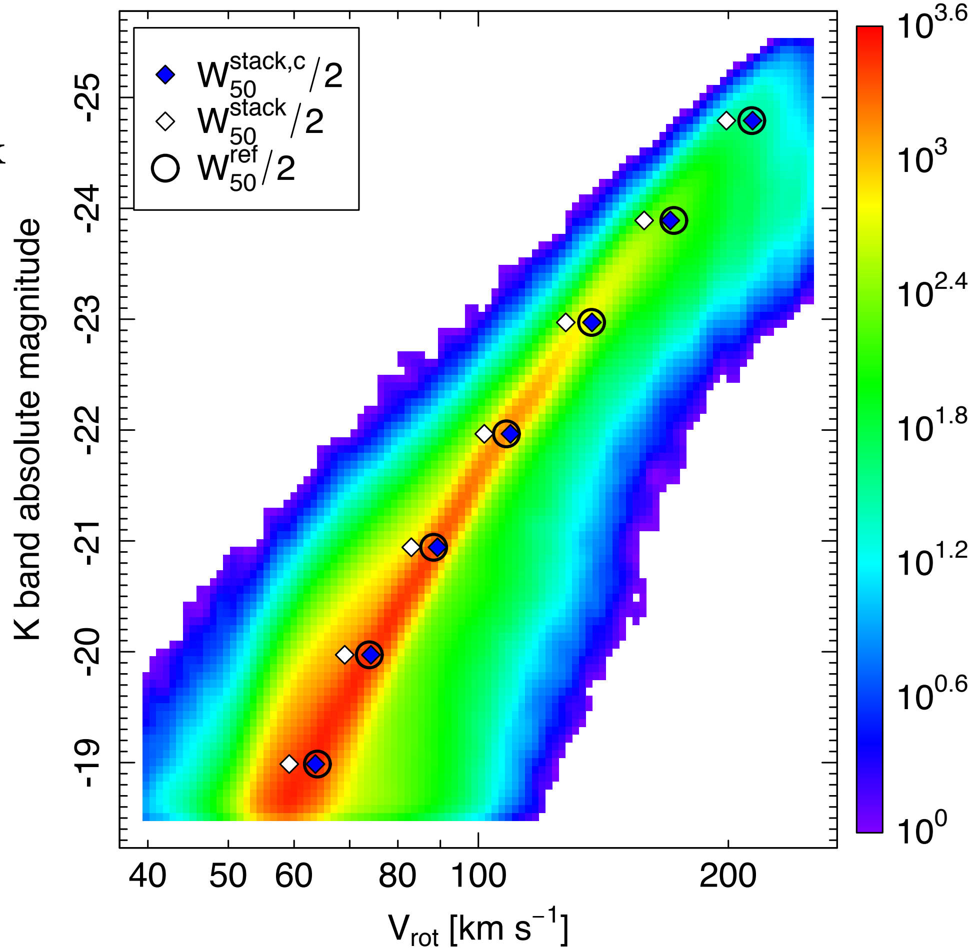




Simulated galaxies 6

S^3-SAX Tully-Fisher relation

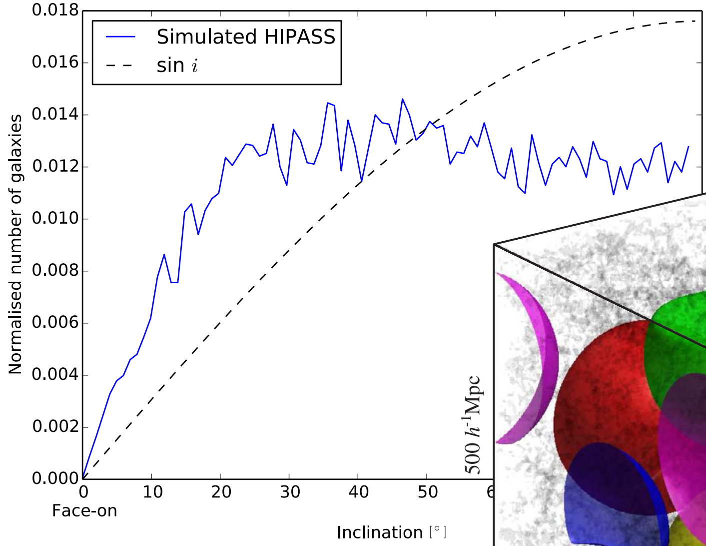
- 1.2 Million galaxies
- Blue diamonds = W_{50}^{stack}
- White diamonds = W_{50}^{stack} before correction
- **Black** circles = averages from individual galaxies

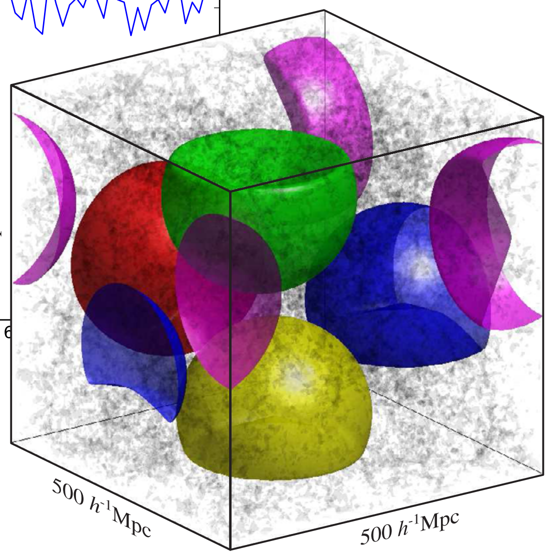


Simulated galaxies 7

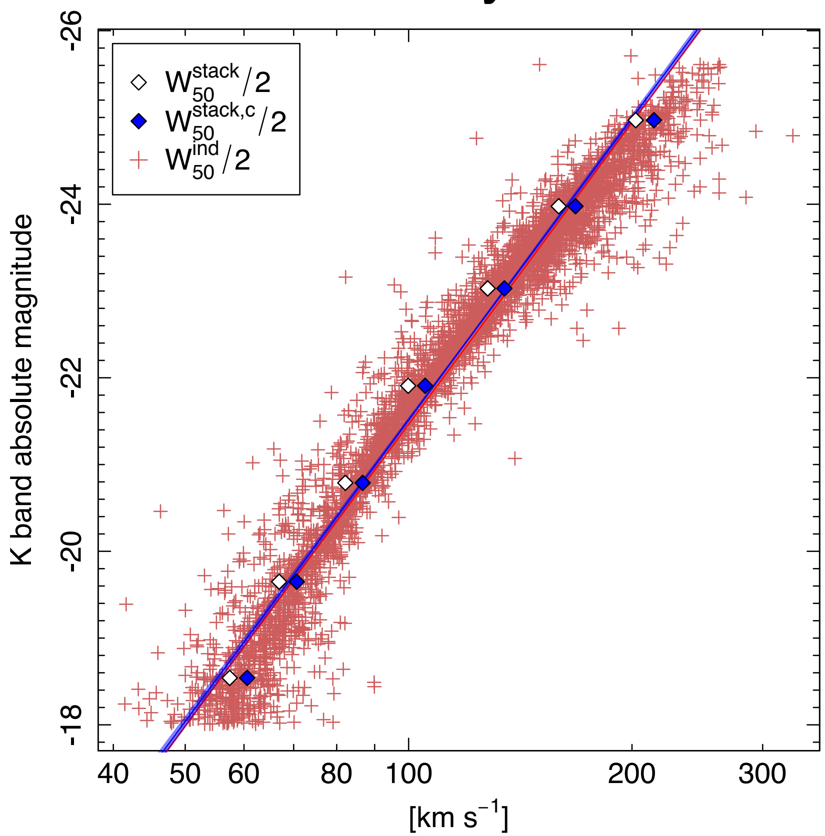
Simulated HIPASS

5 independent regions of the S^3-SAX box were selected and HIPASS was reproduced. TFR reproduced extremely well using HI stacking technique.





Obreschkow 2009

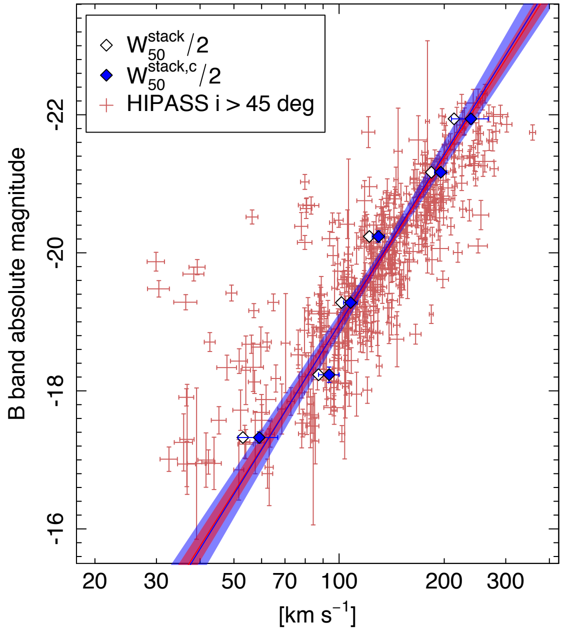


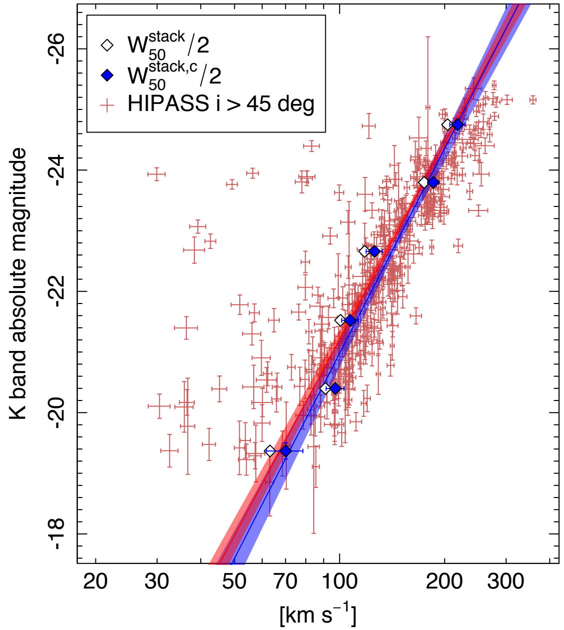
Real data (HIPASS & HICAT)

HIPASS

Galaxy selection was kept to a minimum: Galaxies to be stacked were only cut based on angle from CMB equator. Red galaxies were cut based on angle from CMB equator as well as a 45 degree cut.

- Blue = $W_{50}^{\rm stack}$
- Red = HIPASS galaxies
- White = $W_{50}^{\rm stack}$ without corrections





Extension work

Non-detections

Work is on-going in the HIPASS region by stacking 6df galaxies (non-detections in radio).

SKA

With significantly deeper data sets such as DINGO, WALLABY and LADUMA, stacking can be used to squeeze more science out of these instruments.

Other uses for stacking

So far stacking has only been used to recover total HI flux (and now average rotation velocities), how far can we take this technique?

Optical and Radio survey overlap

This work relies heavily on overlapping optical (or IR) and radio surveys.

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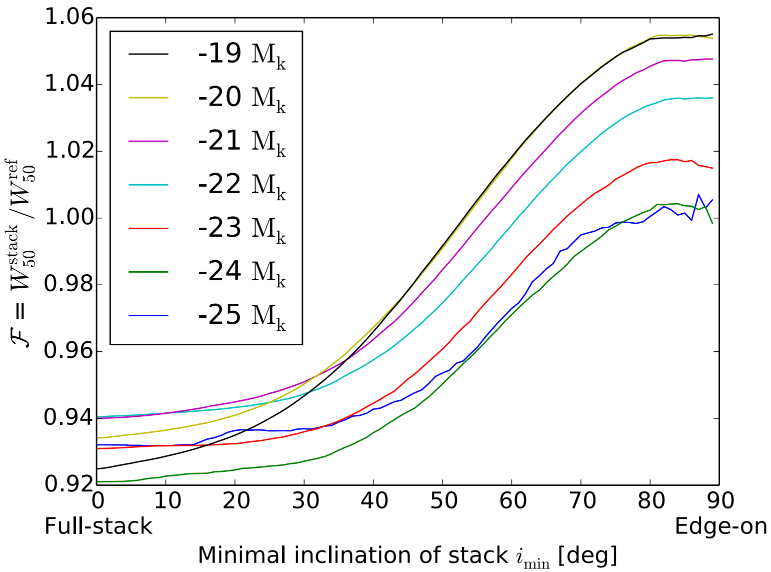
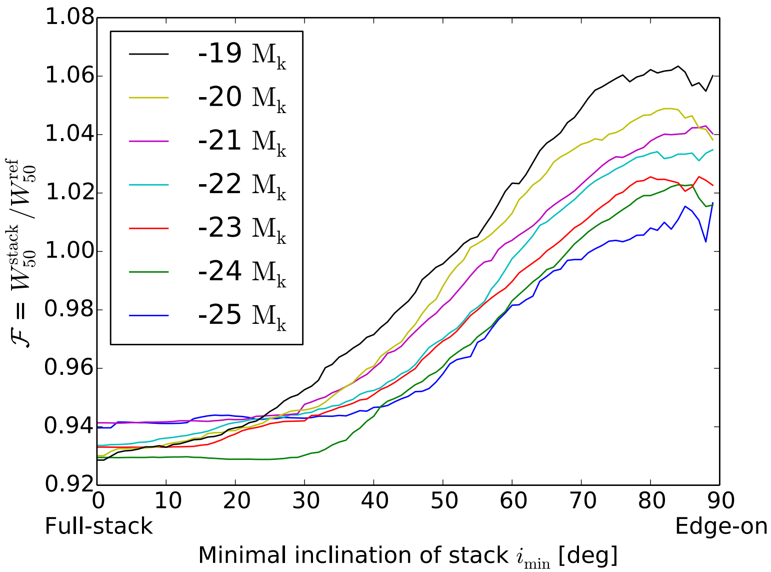
- HIPASS direct detections

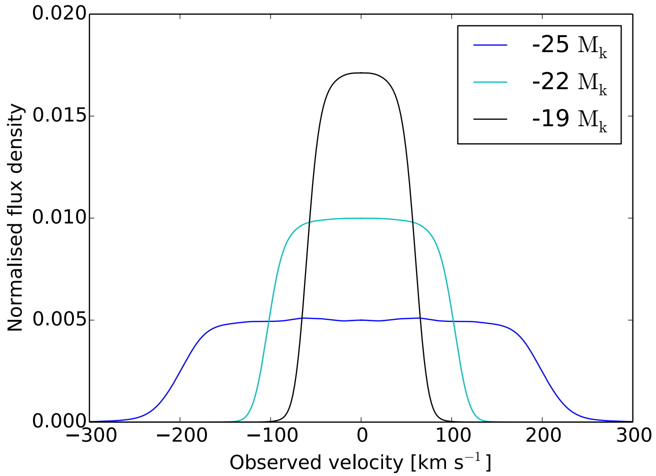
Extension work

- Non-detections
- SKA
- Other stacking work

Extra plots



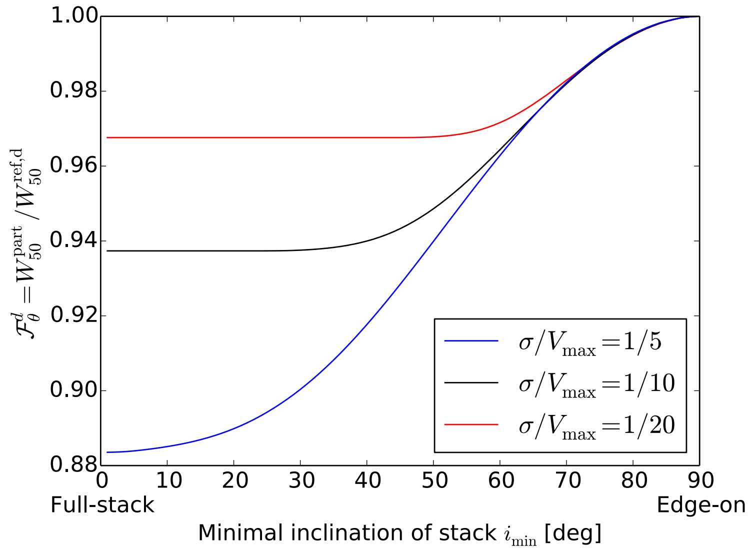




HIPASS simulation

Millennium

Extra plots



W50ref = deprojected but
WITH dispersion

Millennium data
WITH elliptical
galaxies