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THE LAST SURVEY OF THE ‘OLD’ WSRT:

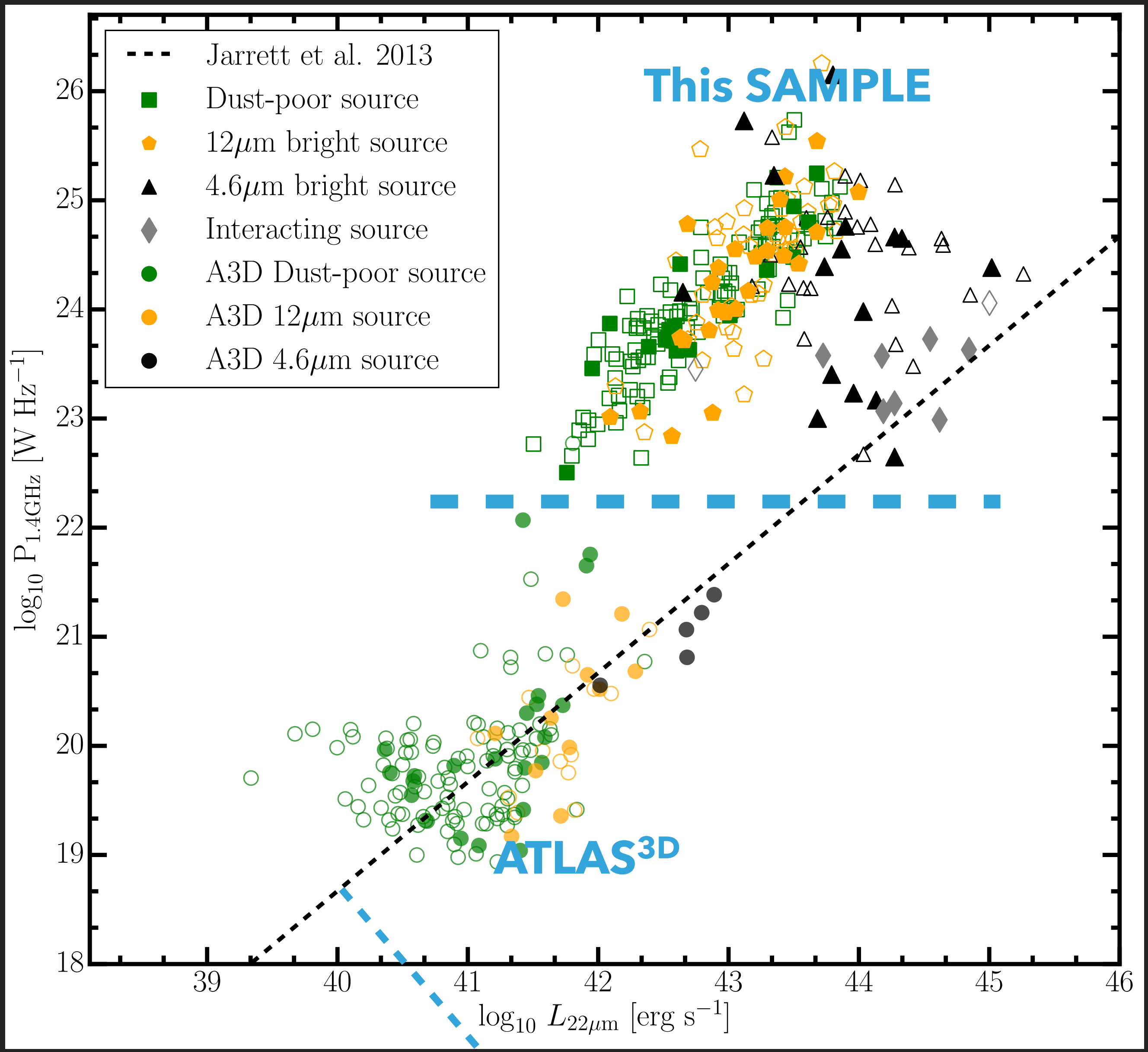
TOOLS AND RESULTS FOR THE FUTURE HI ABSORPTION SURVEYS

A SURVEY BEFORE THE 'BLIND' SURVEYS

- During my PhD, WSRT was upgraded to Apertif: over time antennae went offline
- To detect HI absorption we don't need complete uv-coverage
    - Great opportunity for HI absorption studies
        - Observe as many sources as possible before WSRT observations stop
            - 4/6 hrs observation with variable number of antennae
            - average noise in the spectra ~ 1 mJy
        - Set strategy and tools for the 'blind' surveys: SHARP, MALS, FLASH
        - What is the detection rate of HI in the local Universe?
        - What features of the HI lines relate to the properties of the radio sources?

THE LAST SURVEY OF THE OLD WESTERBORK

- 248 sources
  - 0.02 < z < 0.25
  - SDSS spectroscopy
  - $S_{Cont} \geq 30$ mJy
    - mostly AGN in ETG



1. 101 sources; $S_{Cont} \geq 50$ mJy
   - Stacking experiment [Geréb et al., 2014]
   - Analysis of the detections [Geréb , Maccagni, et al., 2015]
2. All 248 sources
   - This Talk [Maccagni et al., 2017]

Mid-InfraRed [22 μm] - Radio Power Relation

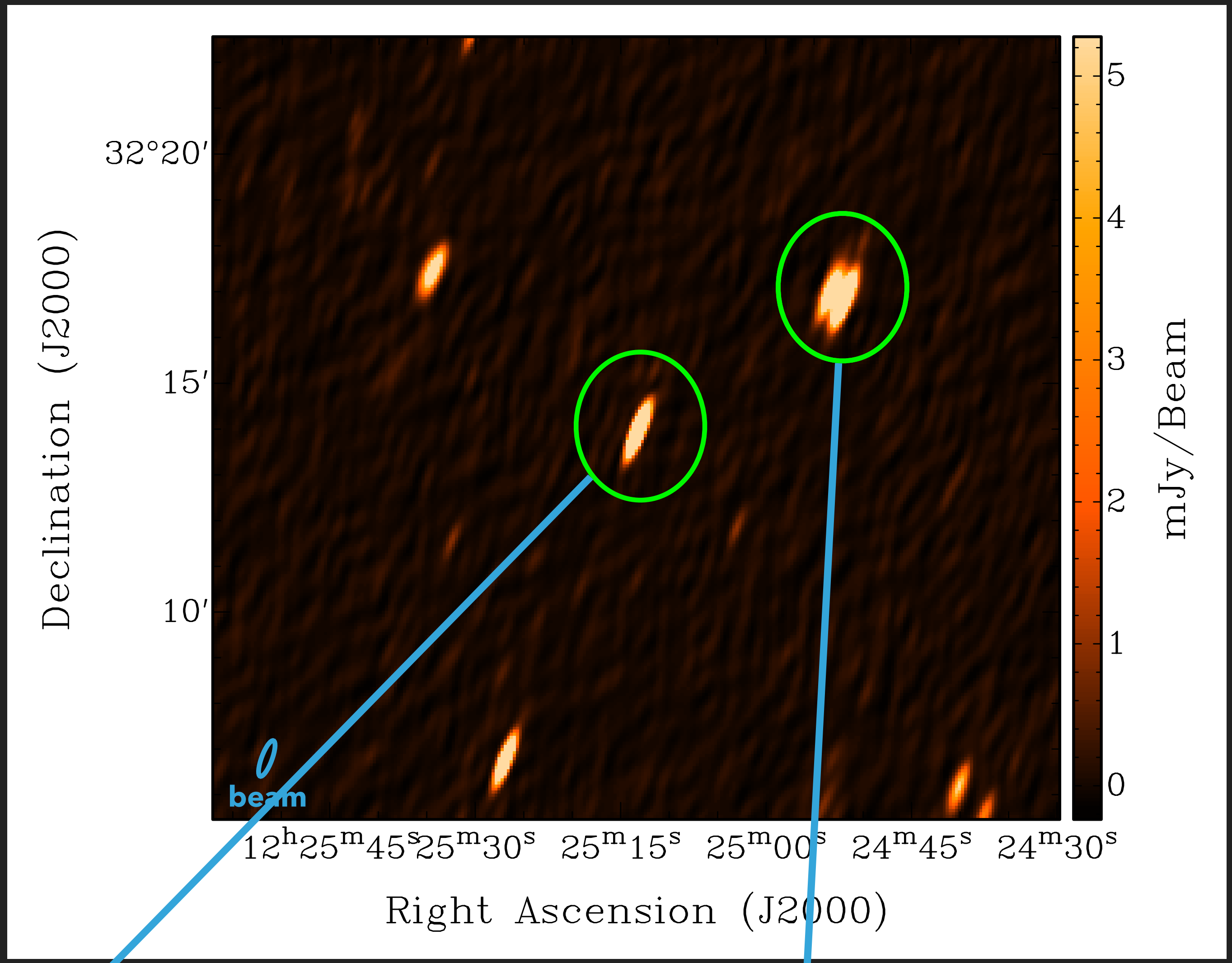
STRATEGY OF THE SURVEY

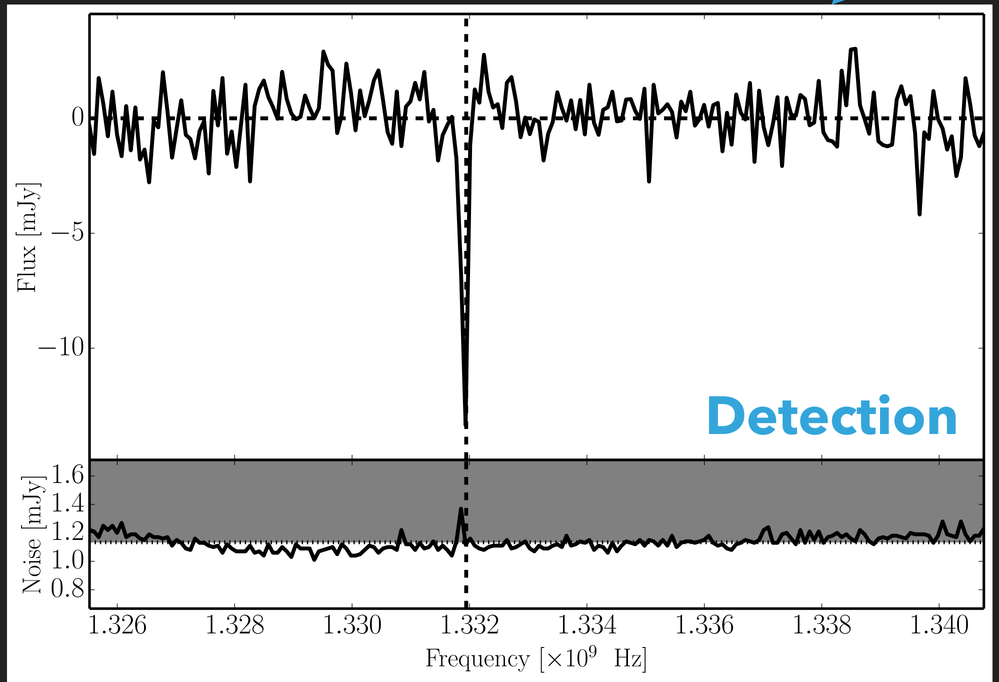
Similar to APERTIF observations
Flagging and automatic calibration
Data Cube + Continuum Image

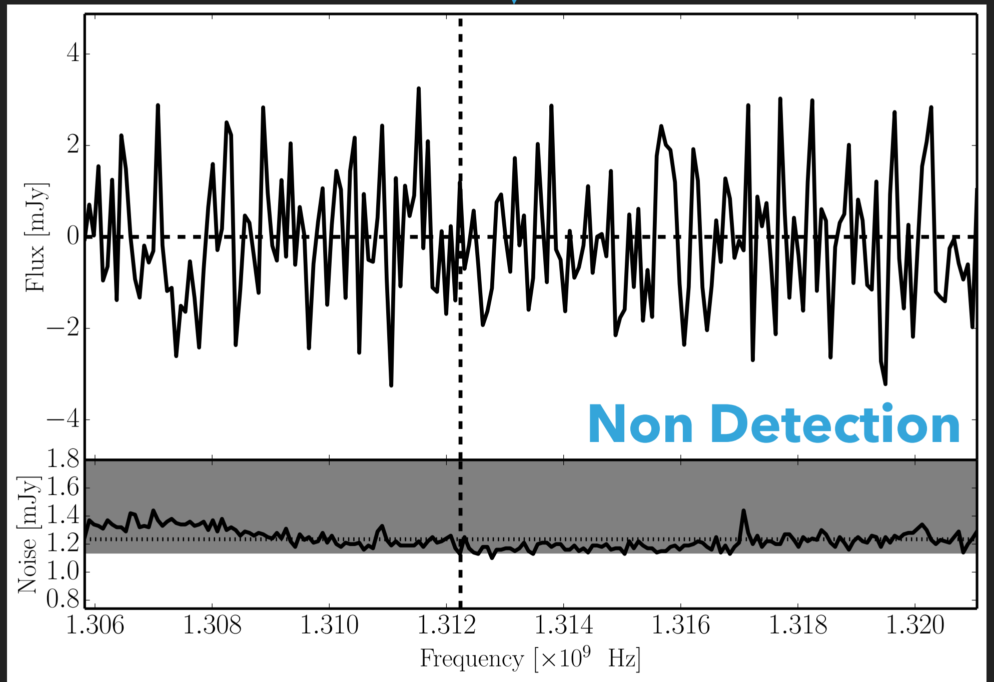
Continuum source finder:
location continuum sources (down to 10mJy/5mJy or even lower)

Extract the spectra @ location continuum sources

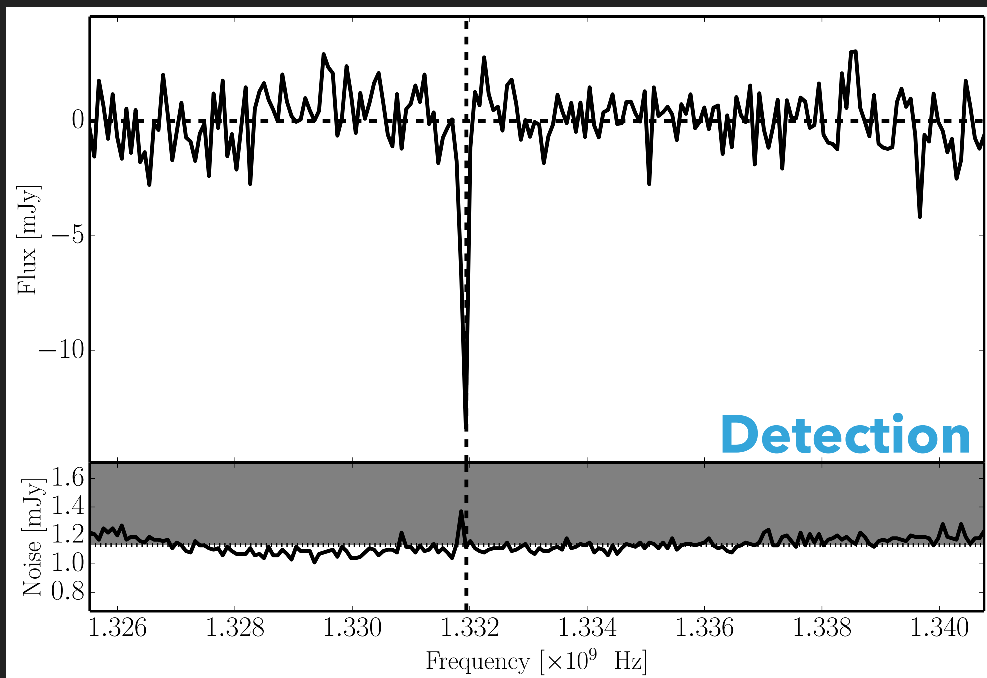
Identify HI absorption detections:
Bayesian line-finder [Allison et al 2012]

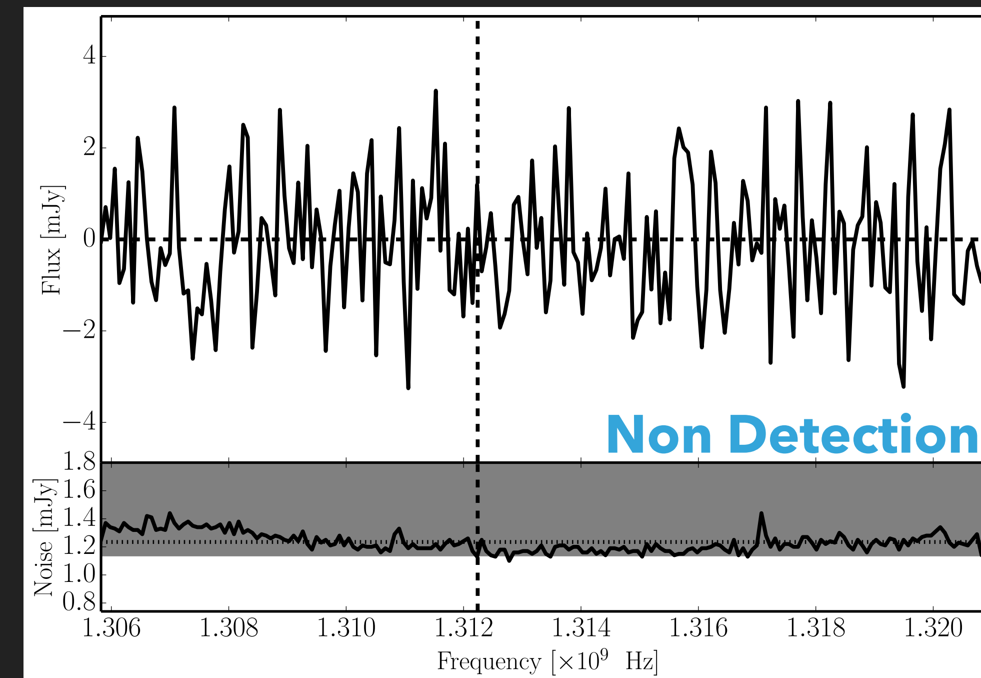






STRATEGY FOR HI ABSORPTION SURVEYS





Intervening or associated?
cross-correlation with spectral surveys

Characterisation absorption
(width, centre, asymmetry etc. using e.g. *busy function*)

DATABASE

cross-correlation with LOFAR fields & other archives (SDSS, WISE)

Properties of the HI lines

Properties of radio continuum (extent, spectral index, …)

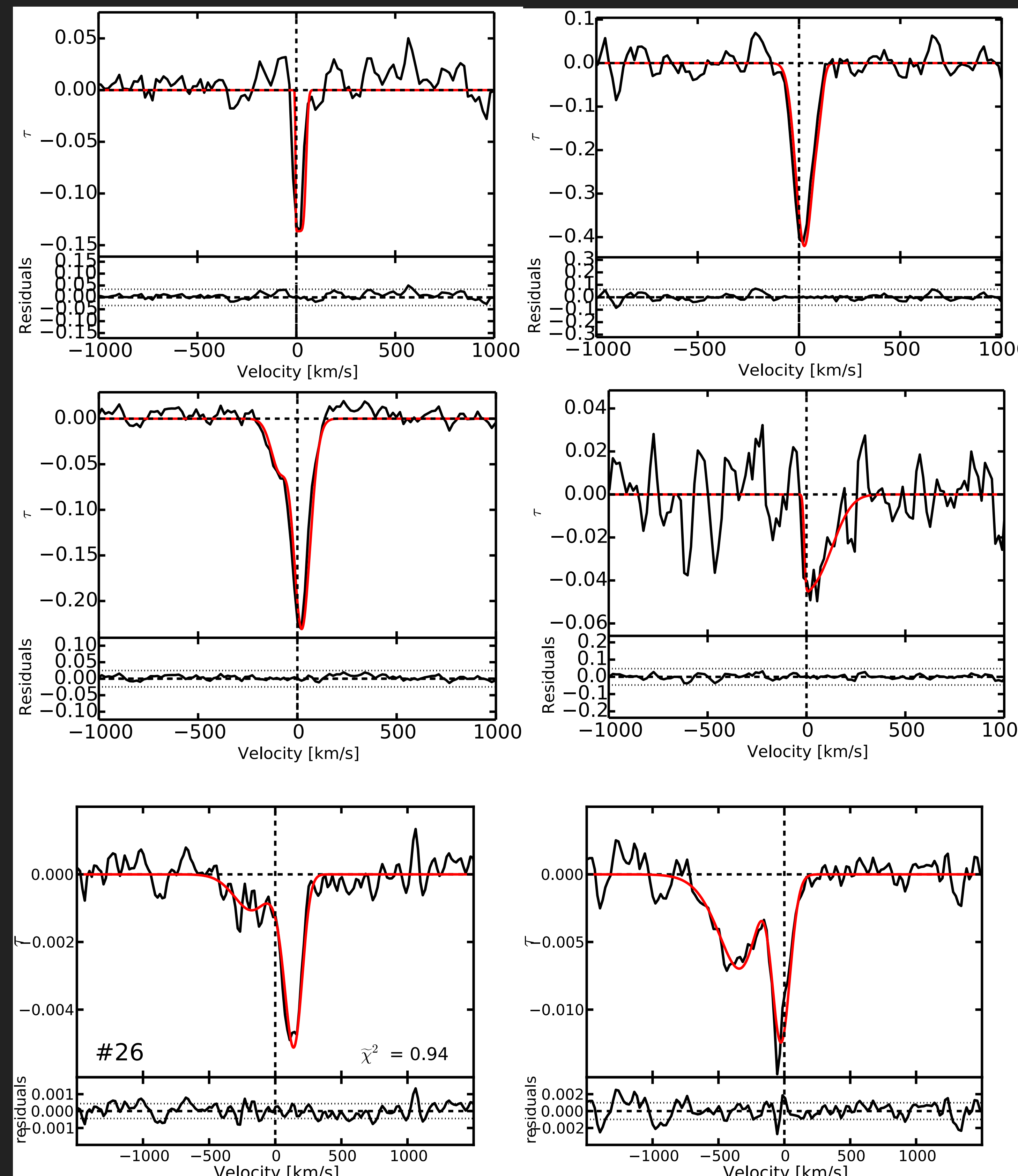
HI ABSORPTION LINES

- 66 detections
- line features measured with the BusyFunction [Westmeier, et al. 2014]
- 30 < FWHM < 570 km/s
- 70 < FW20 < 640 km/s
    - 3 main groups:
        - Narrow lines:

          FWHM < 100 km/s
        - Medium width lines:

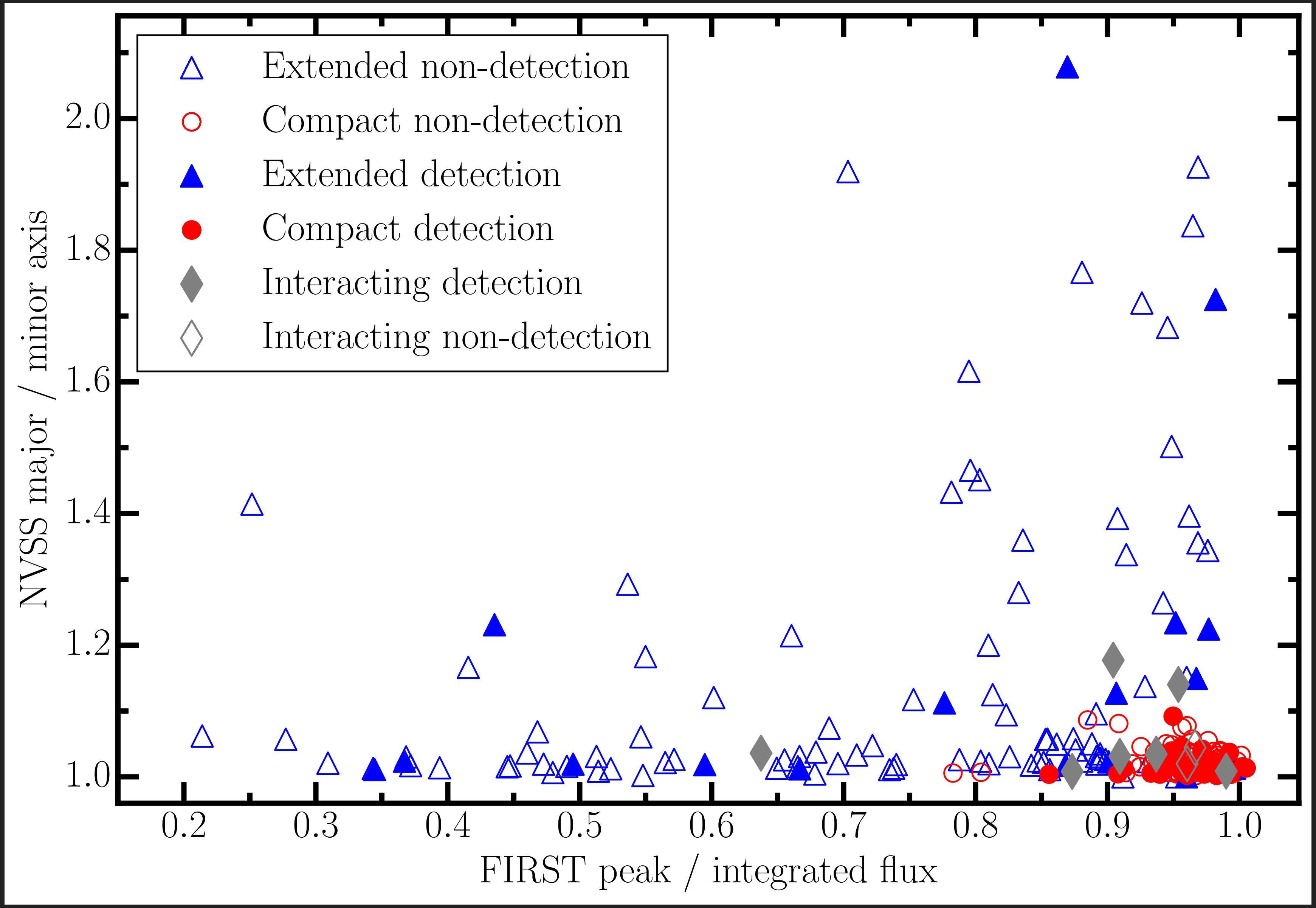
          100 km/s <FWHM < 200 < km/s
        - Broad lines:

          FWHM > 200 km/s



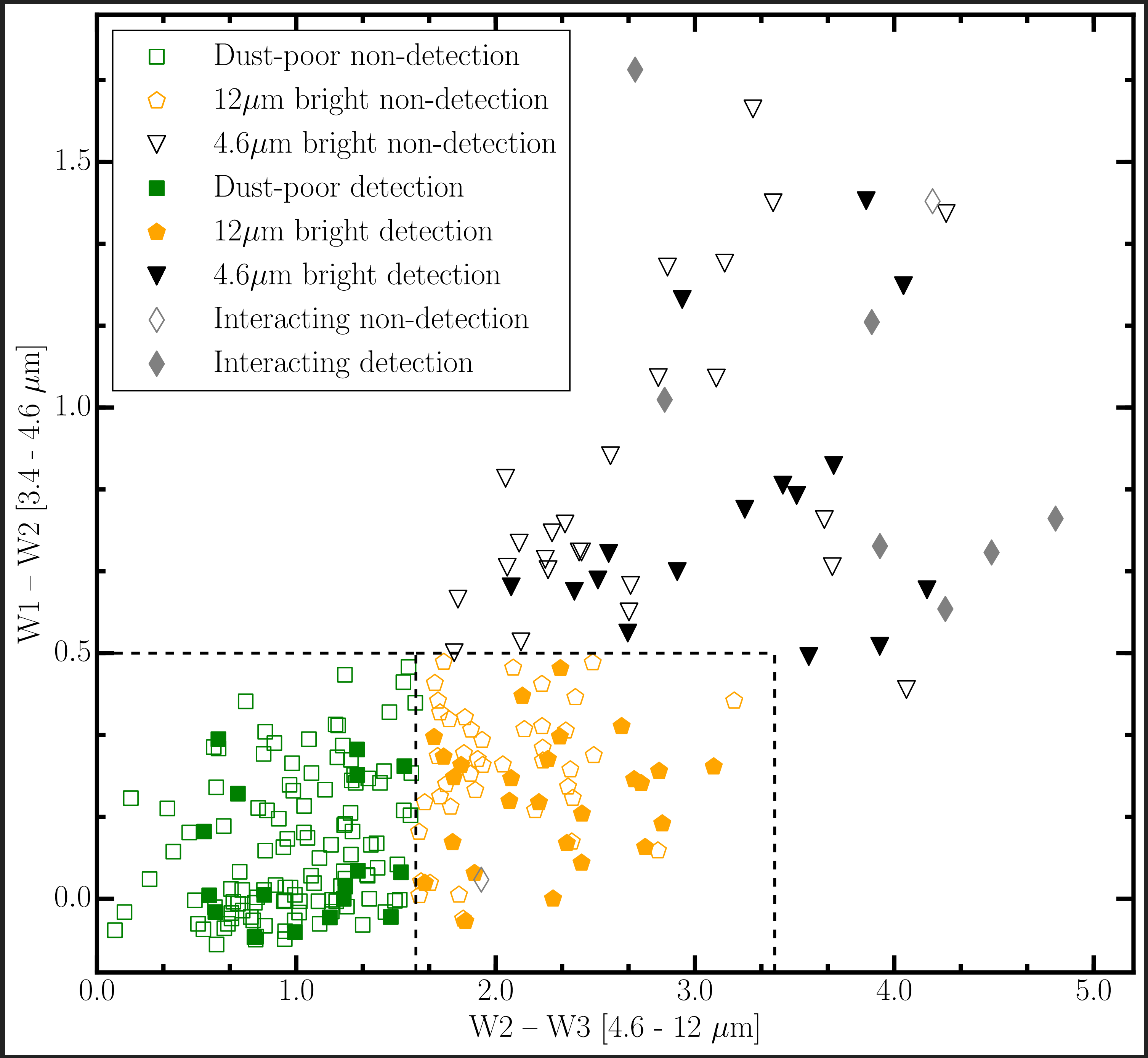
CHARACTERISATION OF THE SAMPLE

- Compact sources (red):
  - unresolved by FIRST.
  - often radio-jets on sub-galactic scales.
  - many compact sources are young AGN.
- Extended sources (blue):
  - resolved by FIRST.
  - radio-jets on super-galactic scales.
  - usually older AGN than compact sources.



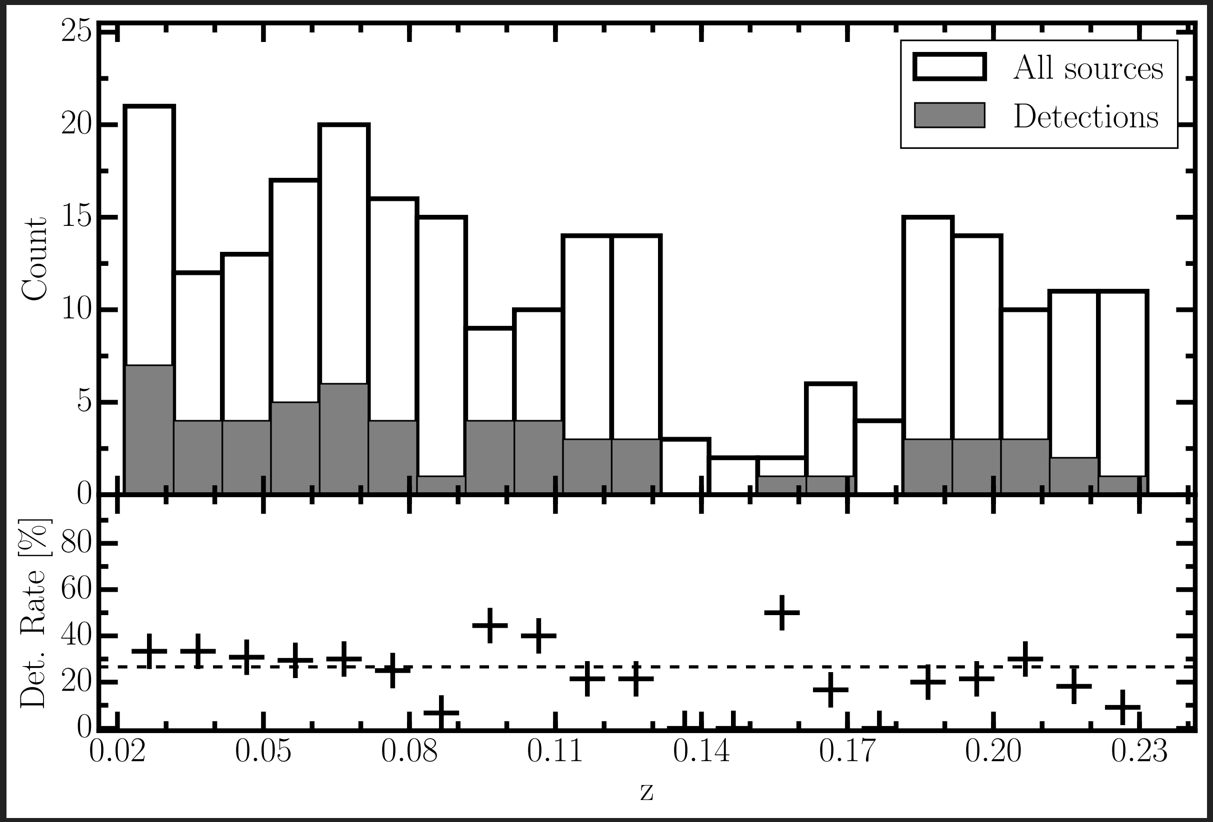
CHARACTERISATION OF THE SAMPLE

- WISE MIR colours
  - dust in the host galaxy
  - Dust-poor sources (green)
  - 12 μm-bright sources (orange)
    - Emission from PAHs and heated dust.
  - 4.6 μm-bright sources (black)
    - The central AGN heats the surrounding circumnuclear dust.

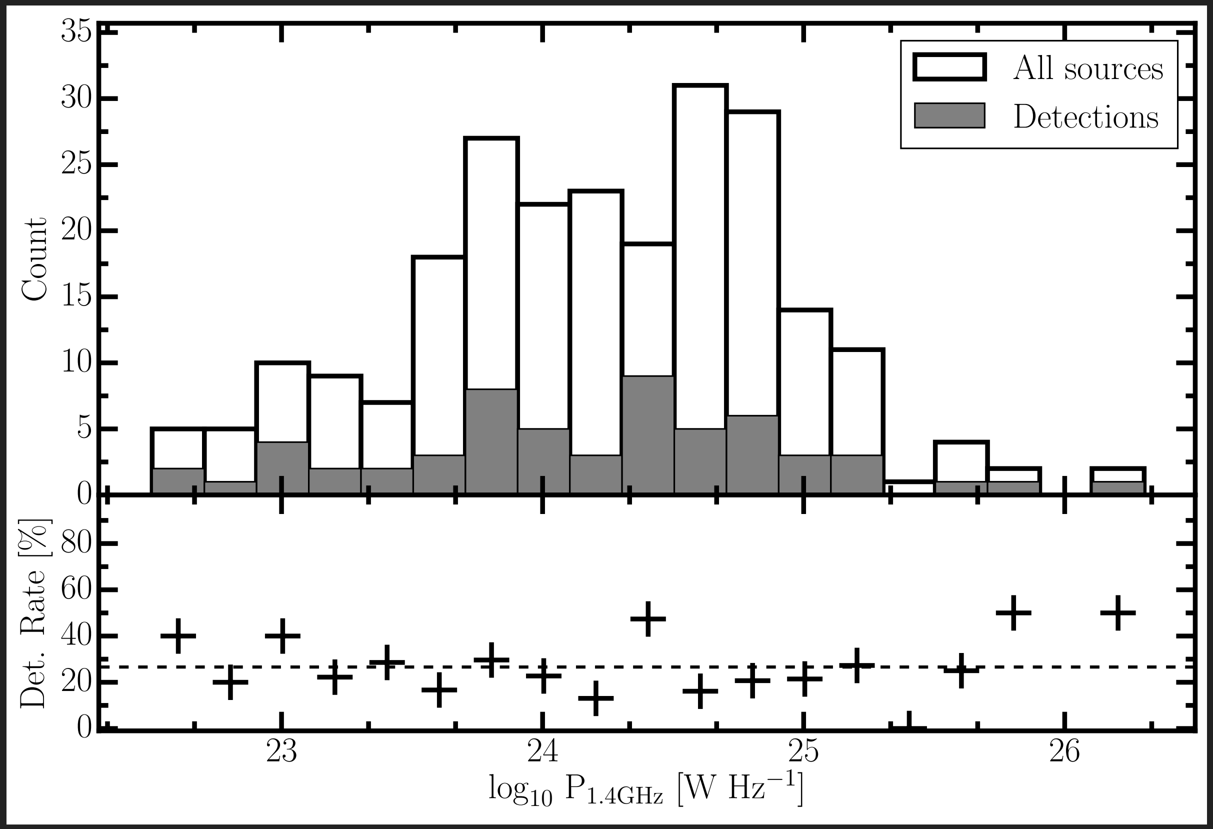


DETECTING HI ABSORPTION

- 248 sources / 66 Detections
    - **27 % ± 5.5 % detection rate**
    - Constant in redshift and radio power



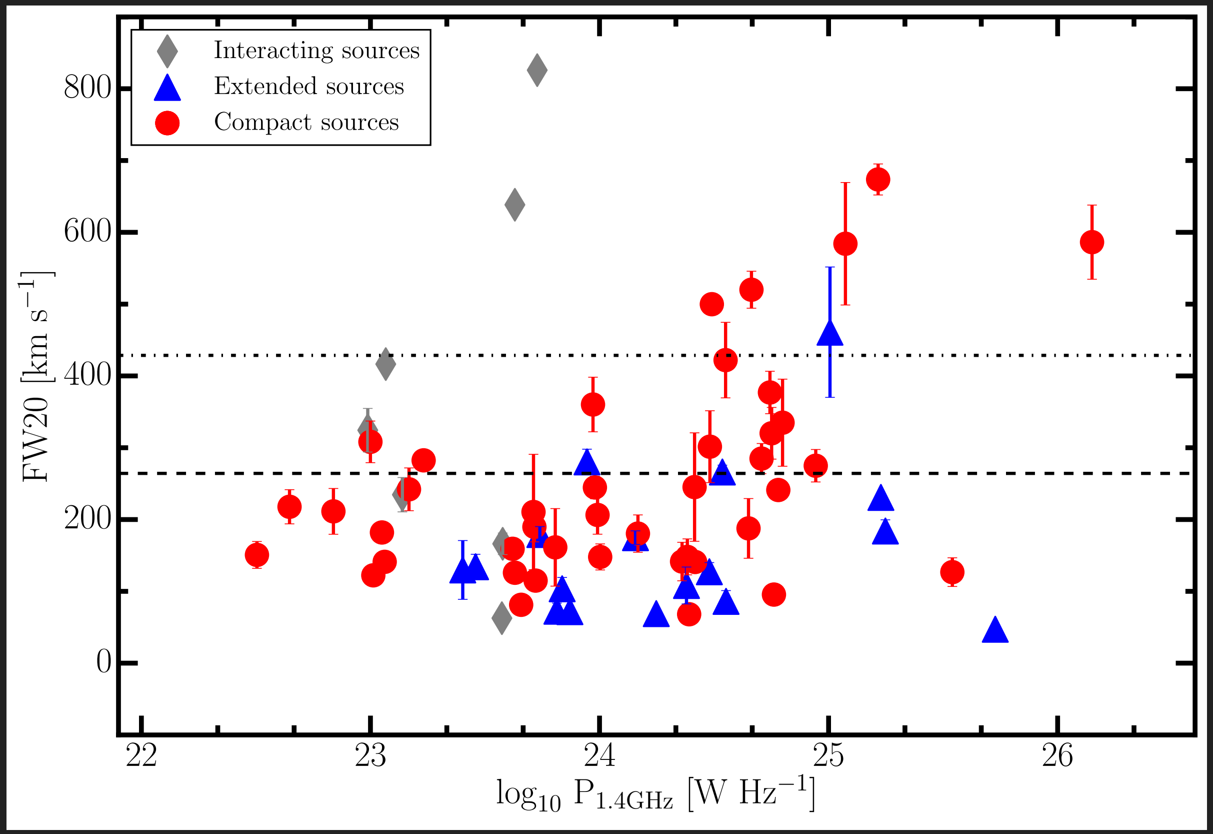
- Compact sources and MIR bright
    - HI often detected (~40%).
- Extended sources & dust-poor sources
    - HI is rarely detected (~13%).



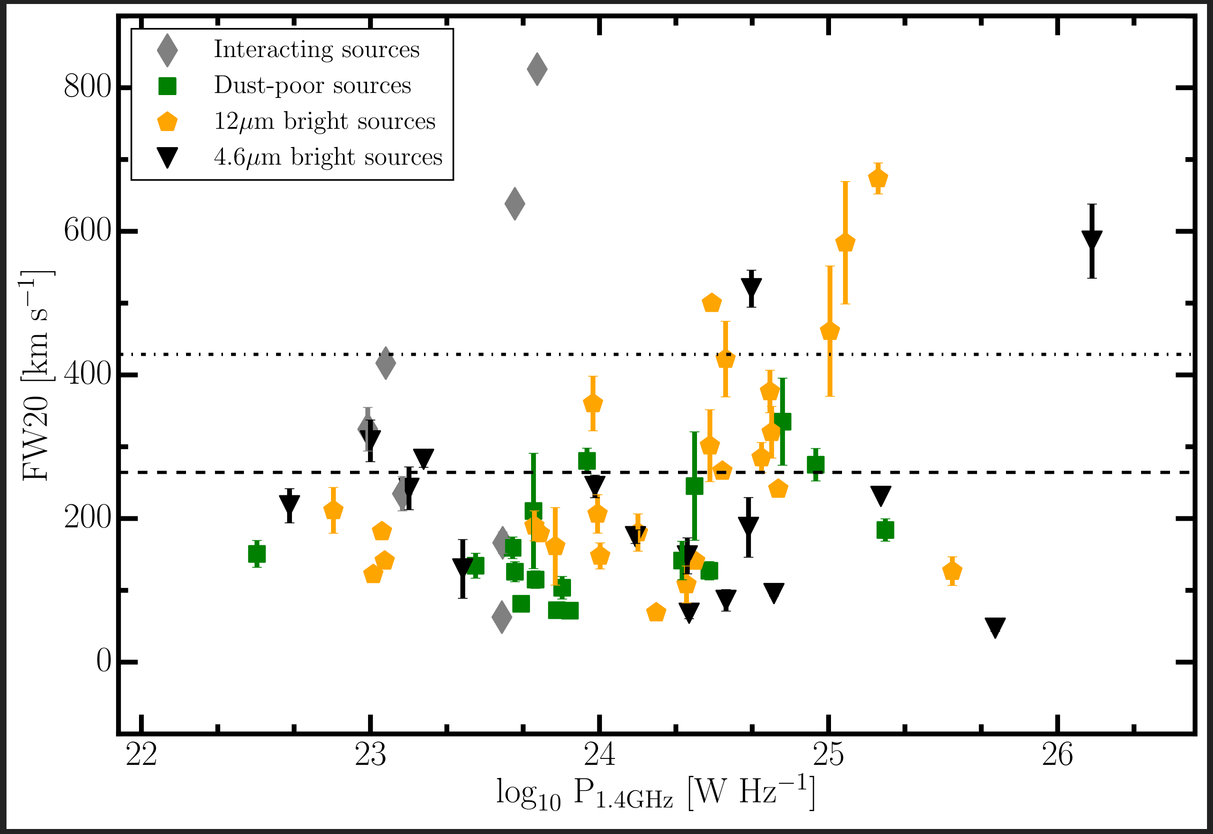
KINEMATICS OF THE HI

- $P_{1.4GHz} < 10^{24}$ W Hz^{-1}
    - widths ≤ rotational velocity
    - HI likely in a rotating disk.

- $P_{1.4GHz} > 10^{24}$ W Hz^{-1}
    - broad asymmetric lines.

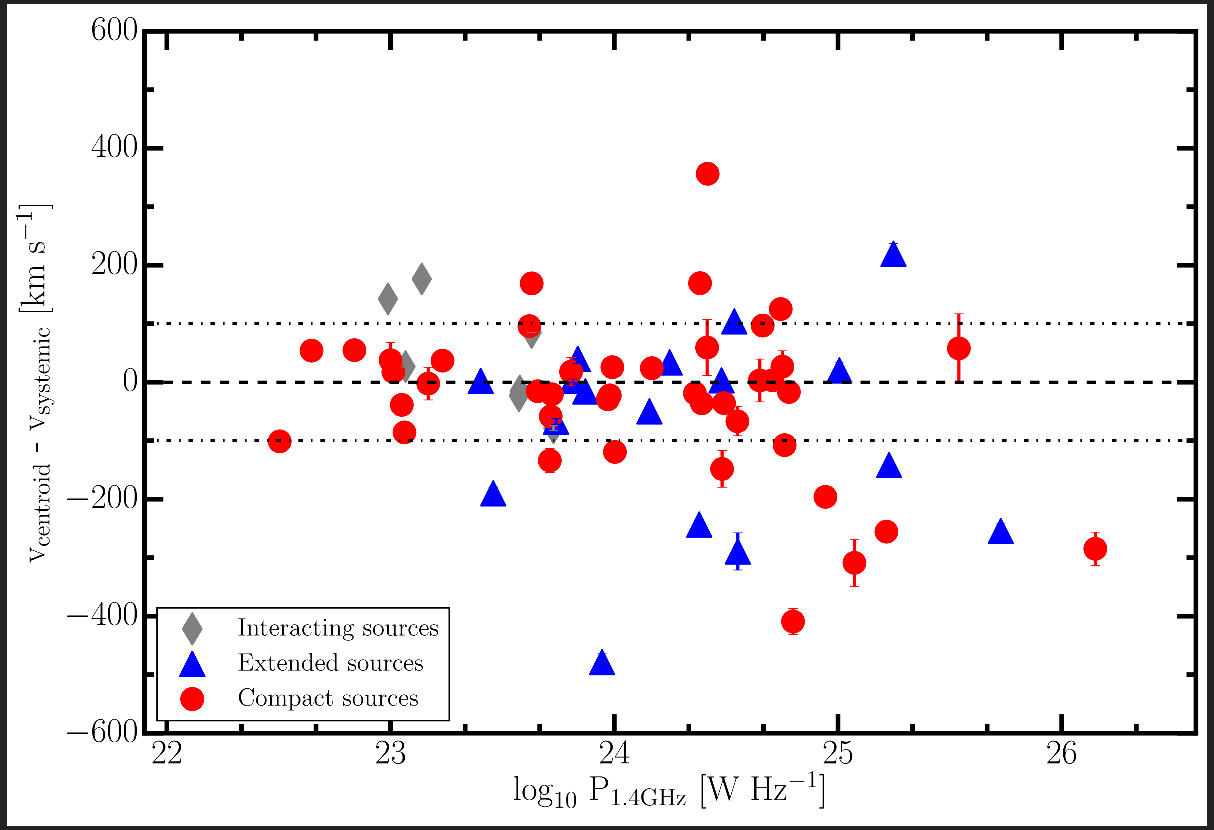


- Sources with broad lines are:
    - Compact, i.e. jets within the galaxy.
    - MIR bright, i.e. rich in heated dust.

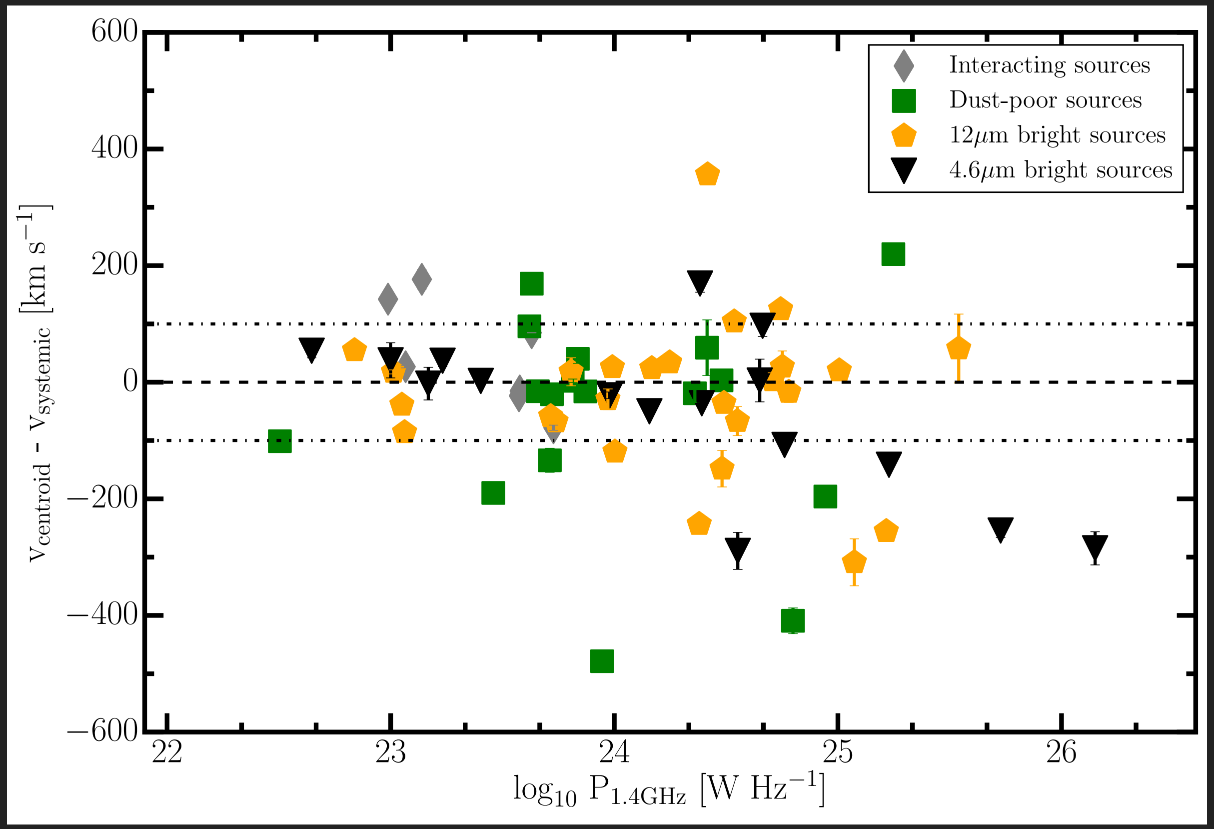


KINEMATICS OF THE HI

- $P_{1.4GHz} < 10^{24}$ W Hz^{-1}
  - lines centred at systemic velocity
- $P_{1.4GHz} > 10^{24}$ W Hz^{-1}
  - lines offset w.r.t. systemic velocity
  - offset is blue-shifted.

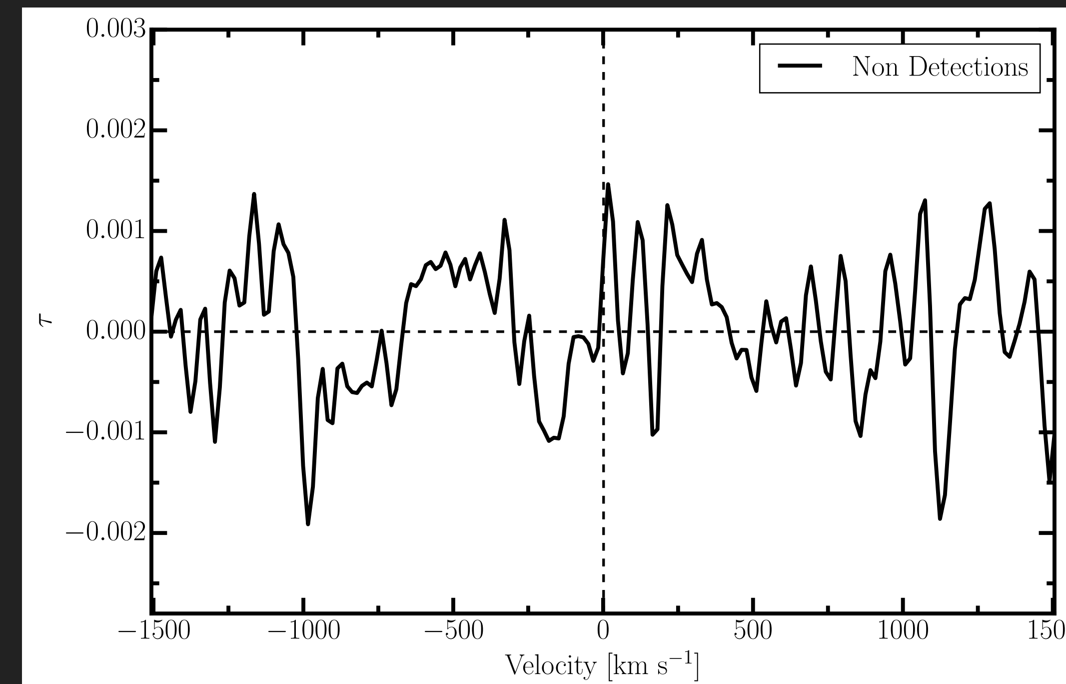


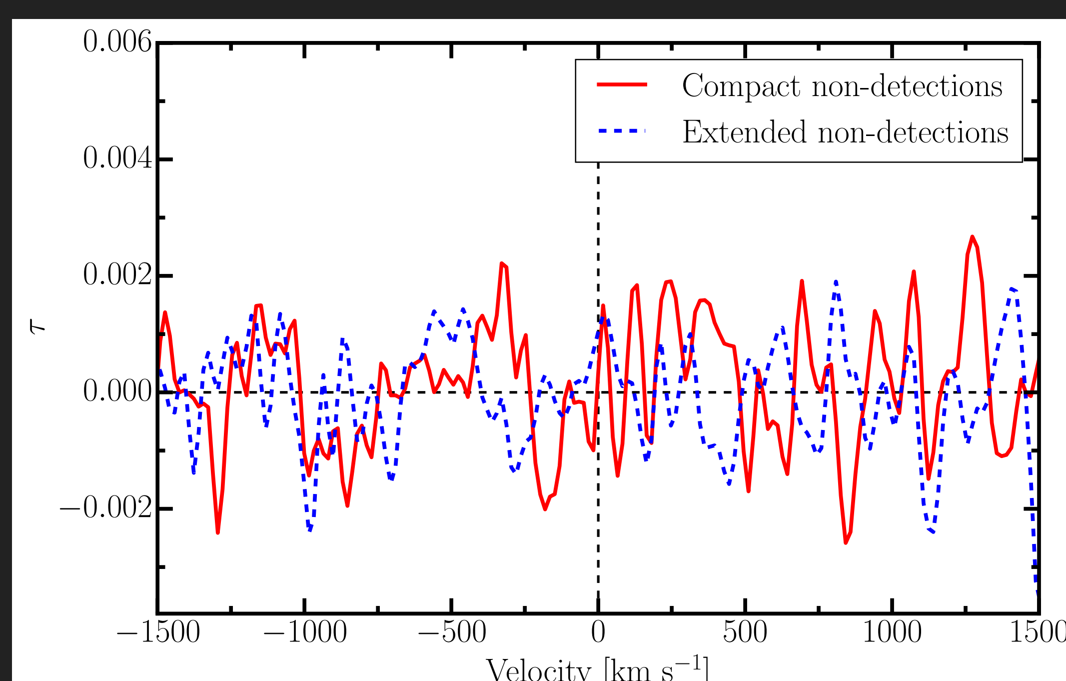
- Broad, asymmetric, shifted absorption line
  - Unsettled kinematics
    - Powerful radio sources
    - Compact, i.e. jets within the galaxy.
    - MIR bright, i.e. rich in heated dust.

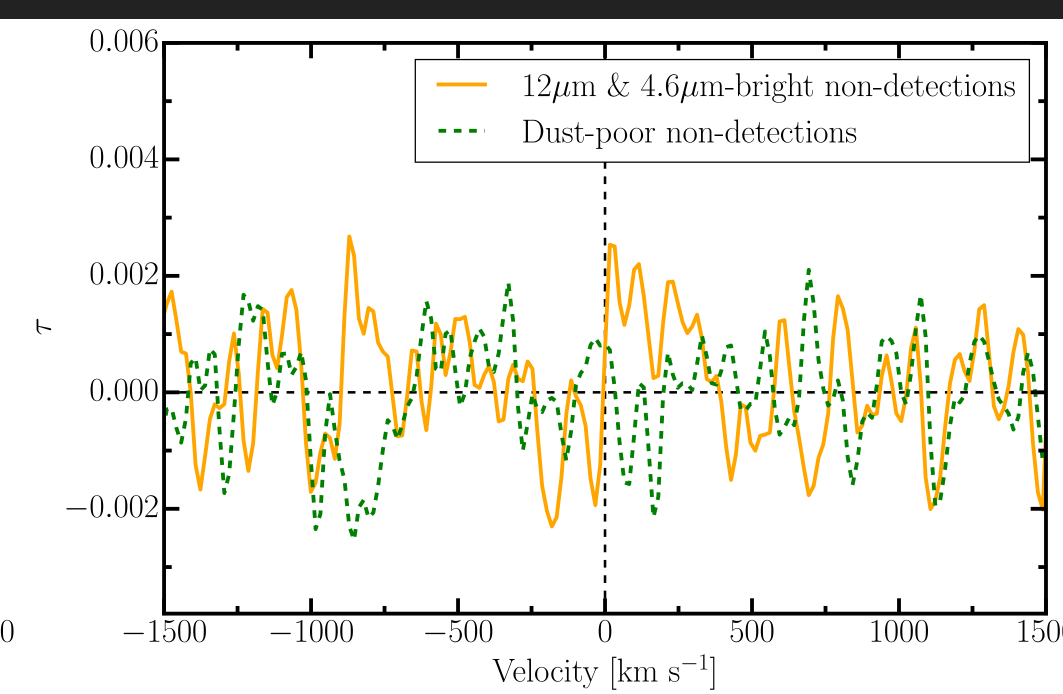


STACKING EXPERIMENT

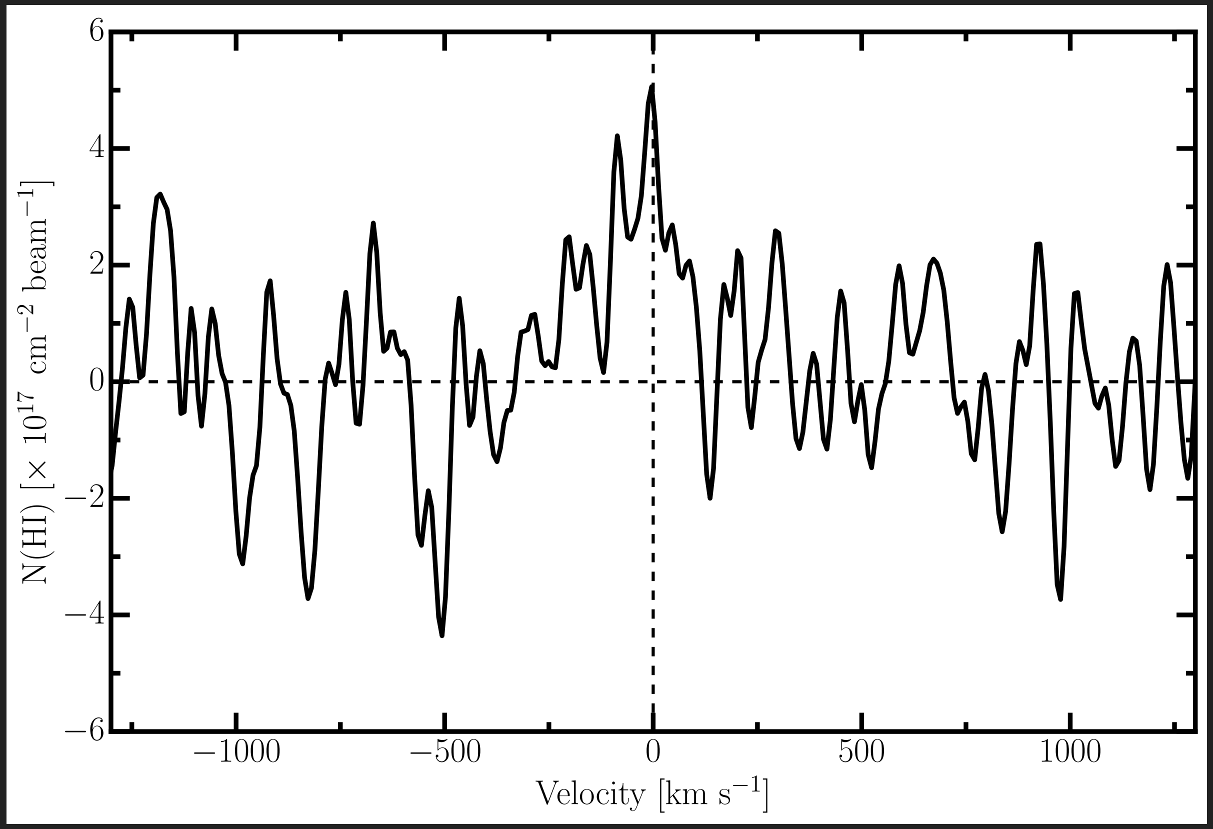
- Non-detections are important!!!!
  - Stacking of 170 non-detections
    - NO LINE is detected at ~ 0.0015 (3σ)
  - Stacking of sub-groups of sources
    - NO LINE is detected at ~ 0.003 (3σ)
    - Not even in compact sources or MIR bright sources.







STACKING THE ATLAS^{3D} NON-DETECTIONS



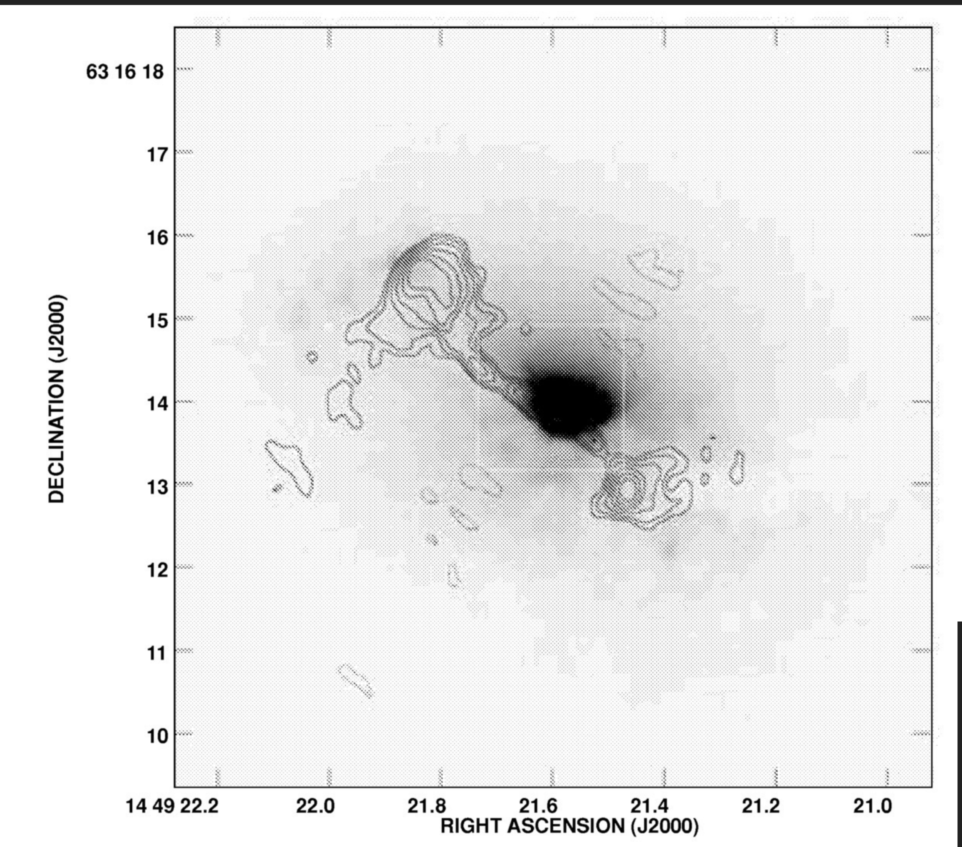
- 81 ATLAS3D sources HI is not detected in the centre.
- STACKING: 3σ detection of HI emission
  - N(HI) ~ 3.5 x 10^{17} (T_{spin}/c_f) cm^{-2}
  - N(HI) converted in optical depth (T_{spin}~100 K, c_f =1)
    - τ~ 0.0006 << 0.0015
    - we need to stack more to detect this gas in absorption.

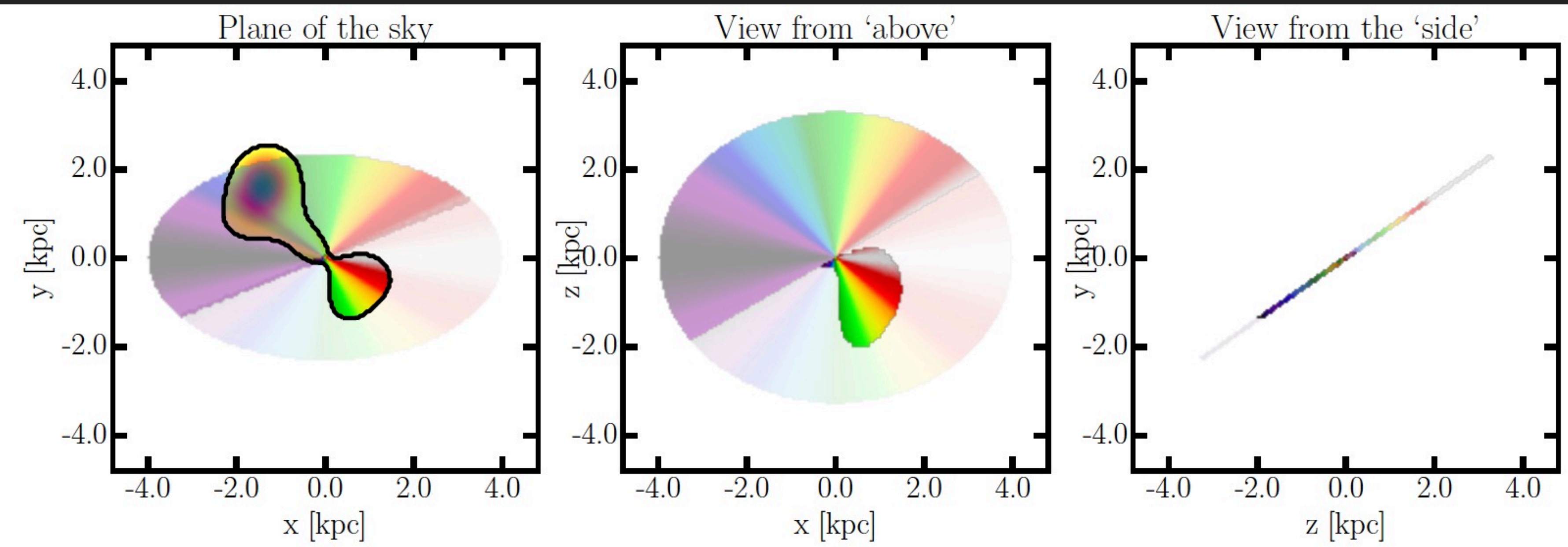
- **The HI stacking ATLAS^{3D} is warm?**
  - T_{spin} ↑ ⇒ τ ↓ ; T_{spin} ↓ ⇒ τ ↑
  - Stacking in absorption even more difficult

INTERPRETING HI ABSORPTION

- Understand the overall distribution of the HI traced by the absorption line
    - What to can we infer from only the integrated line and the continuum image?
        - Model the rotating HI disk in front of the radio continuum:

3C 305 Observation → Model

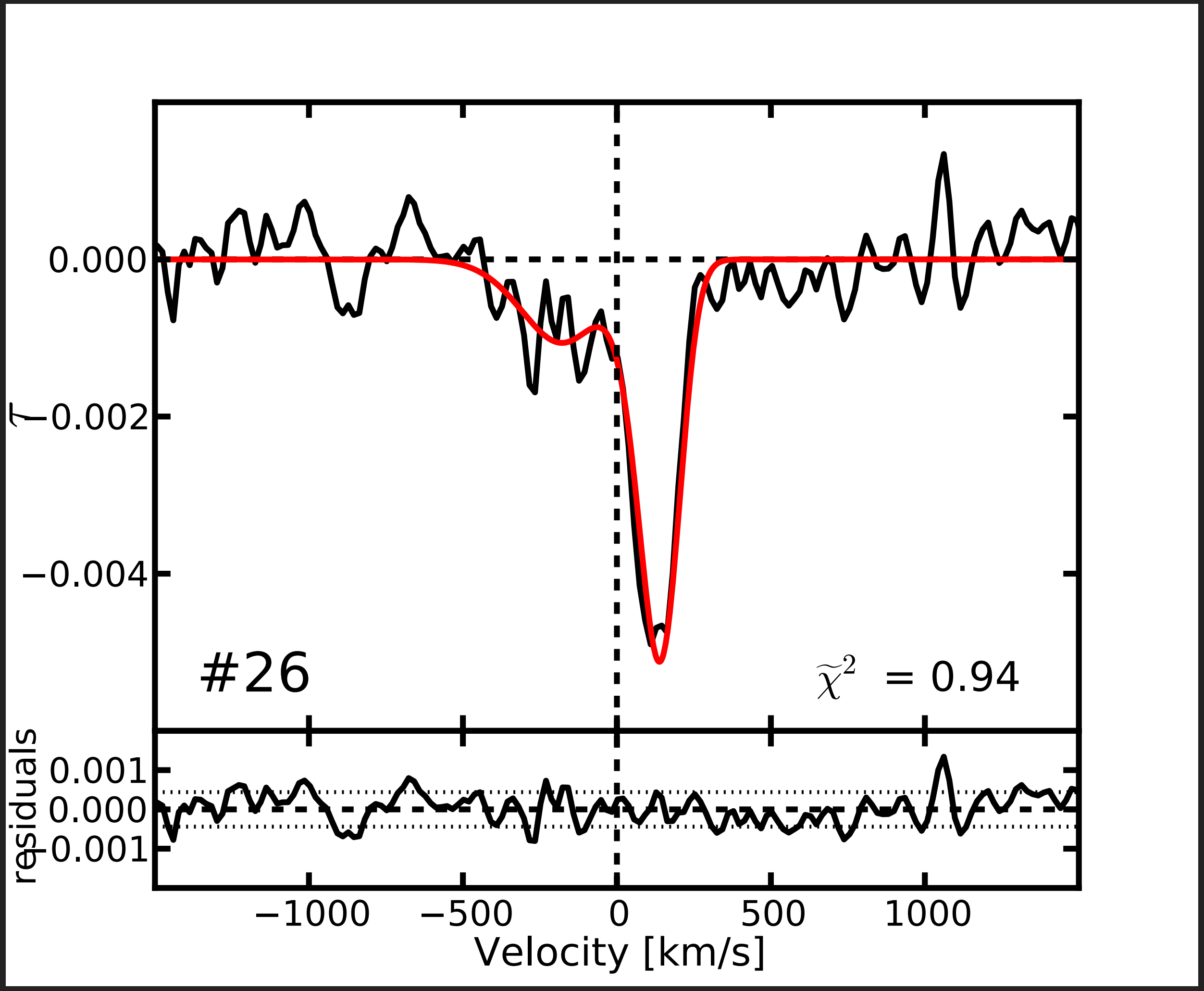


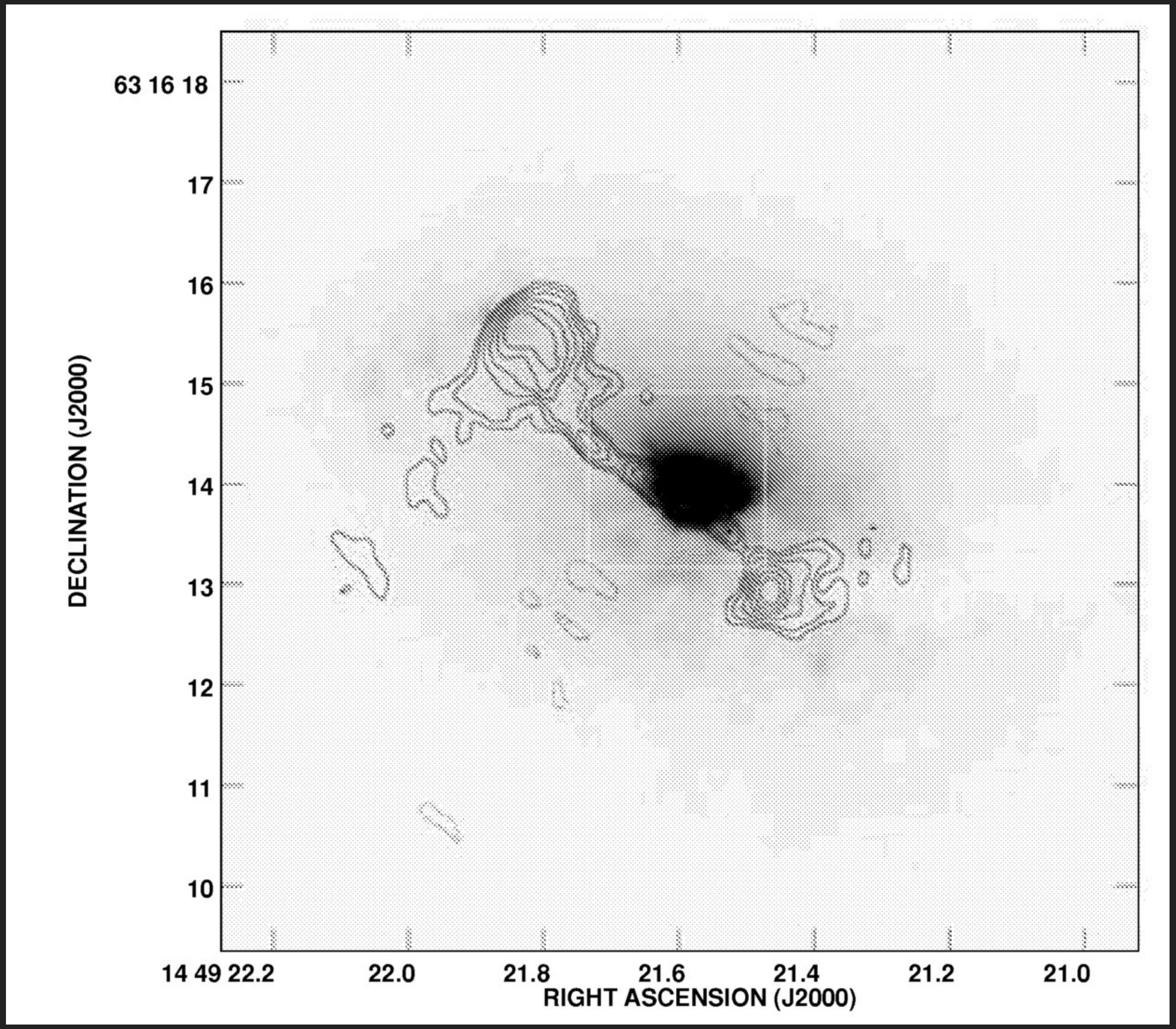


Plane of the sky : x,y   Side view: z,y   From above: x,z

INTERPRETING HI ABSORPTION

- 3C 305
  - Optical Image (SDSS or other): i, PA of the stellar body
  - Continuum image: against which radio lobe there is absorption?
    - i ∈ [0°,180°]
    - PA ∈ [180°, 360°]

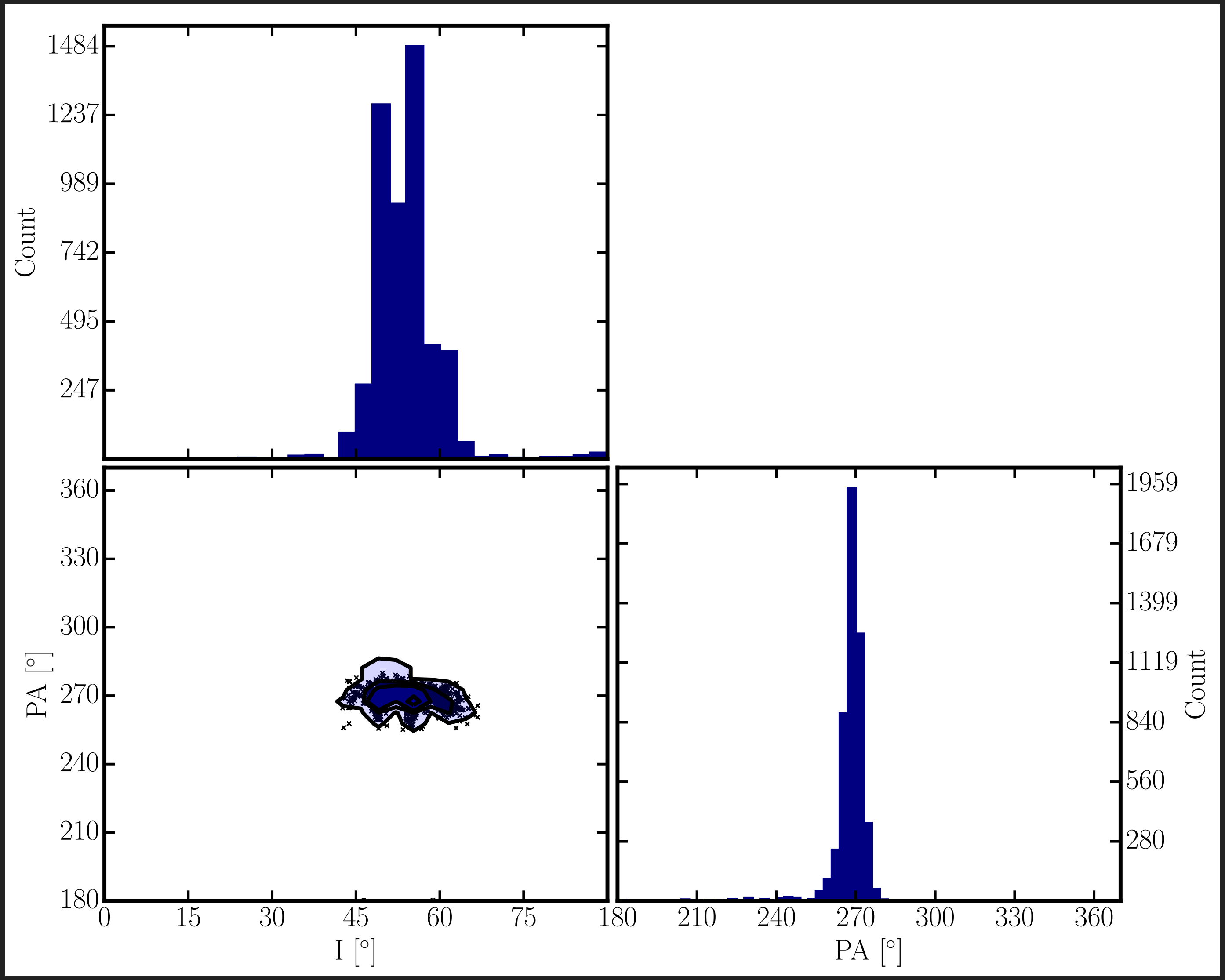




INTERPRETING HI ABSORPTION

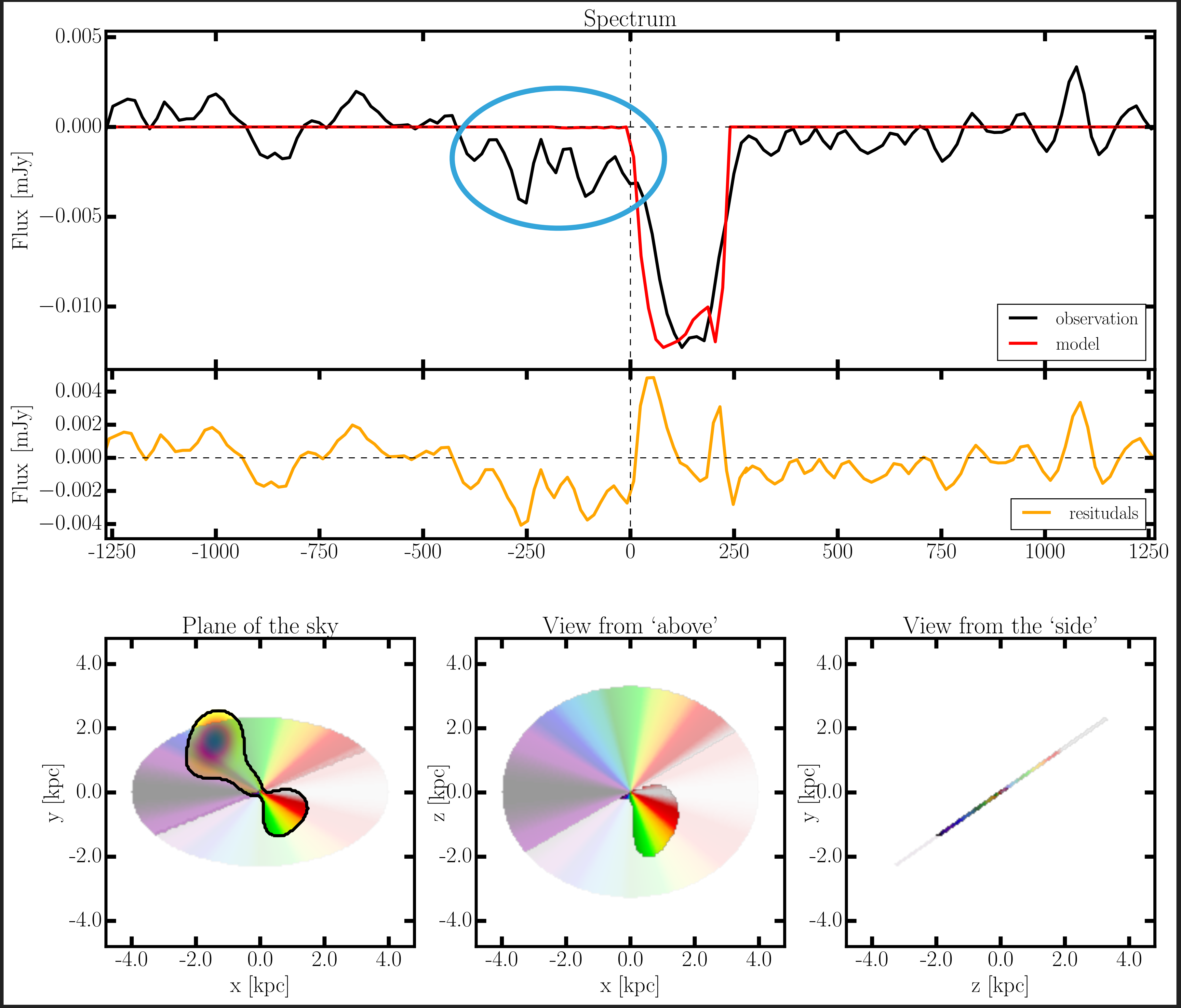
- 3C 305
  - Optical Image (SDSS or other): i, PA of the stellar body
  - Continuum image: against which radio lobe there is absorption?
    - i ∊ [0°,180°]
    - PA ∊ [180°, 360°]

- MCMC algorithm
  - find combination of parameters that best fits the observed line the line
    - i = 45°; PA = 270 °



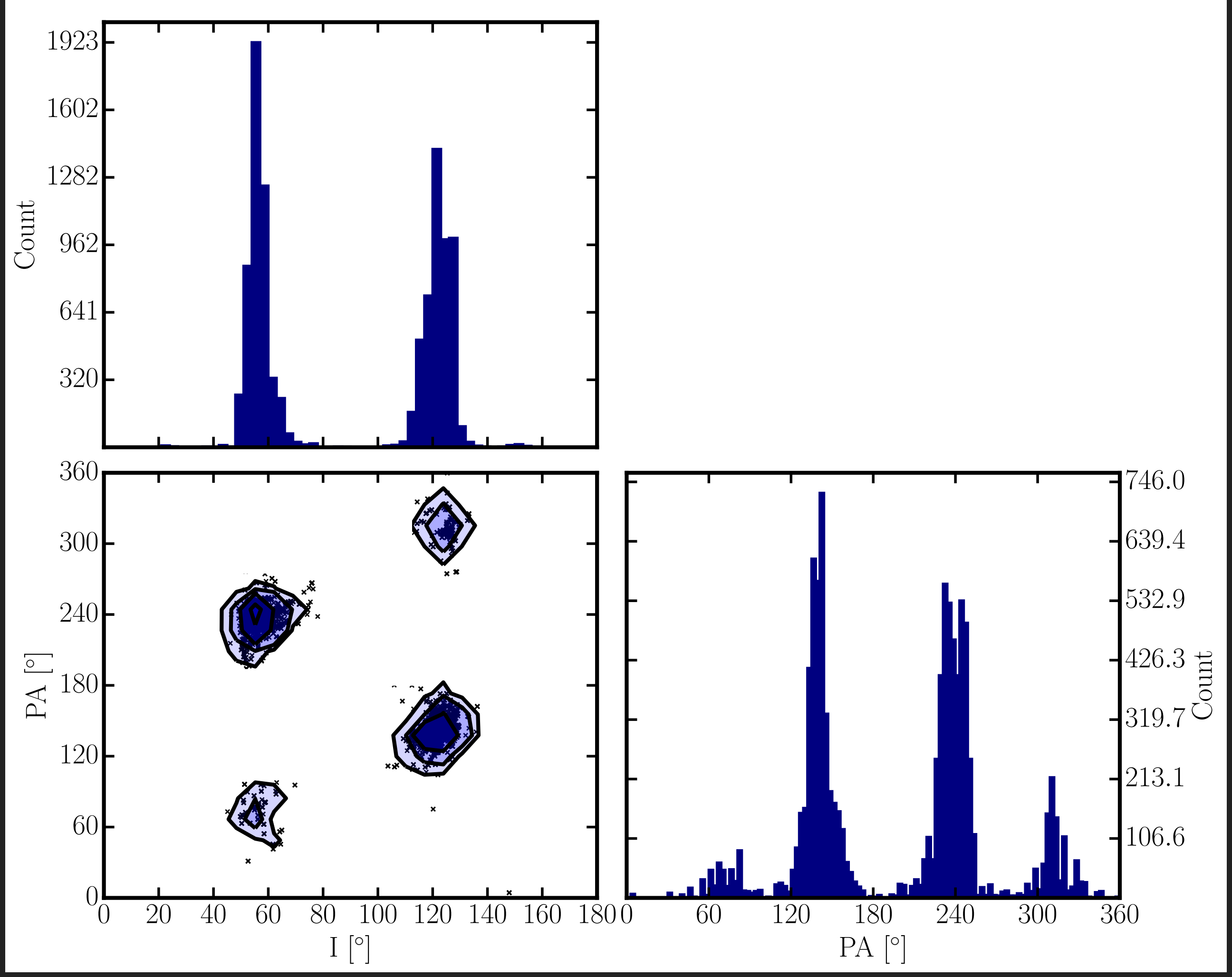
INTERPRETING HI ABSORPTION

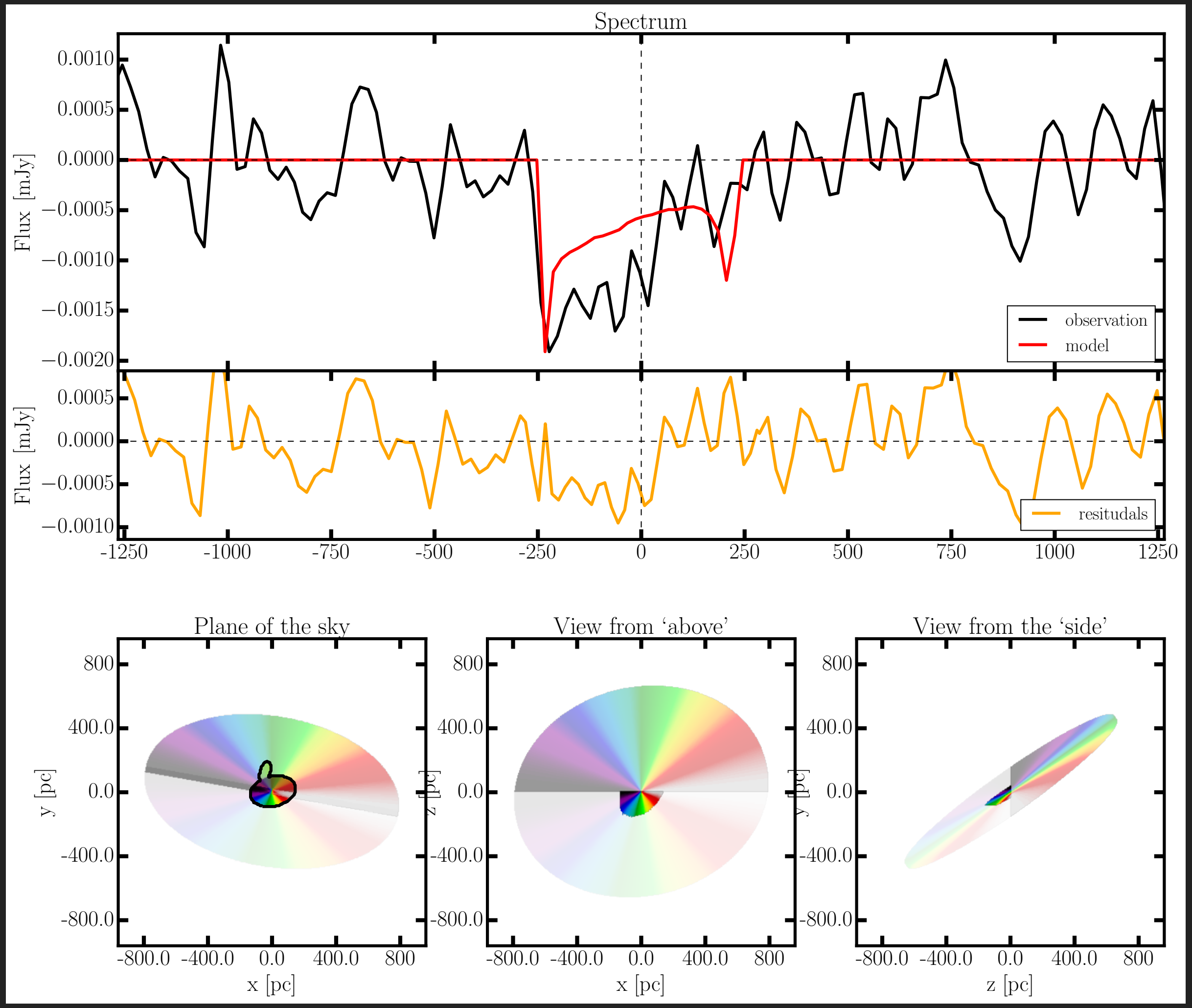
- The bulk of the absorption generated by a rotating disk: i = 45°; PA = 270 °
- Blue-shifted wing not reproduced by the model



INTERPRETING HI ABSORPTION

- Less information on the source?
  - i ∈ [0°,180°]
  - PA ∈ [0°, 360°]





- Best-fit solution: i = 55°; PA = 240 °

- VLBI high resolution continuum
  - Likely we can improve the fit

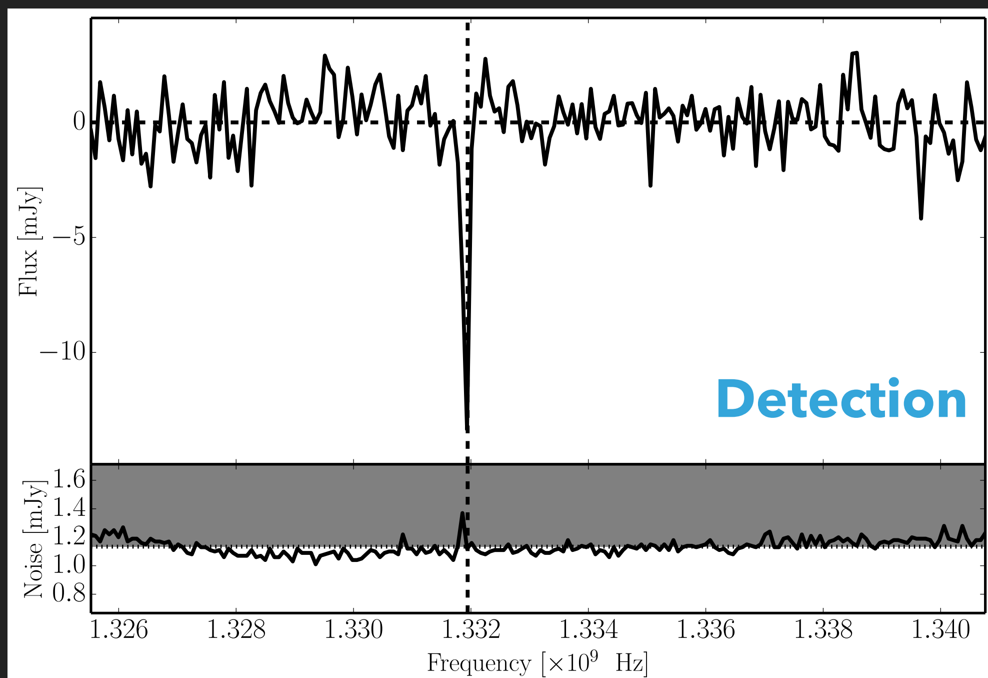
CONCLUSIONS

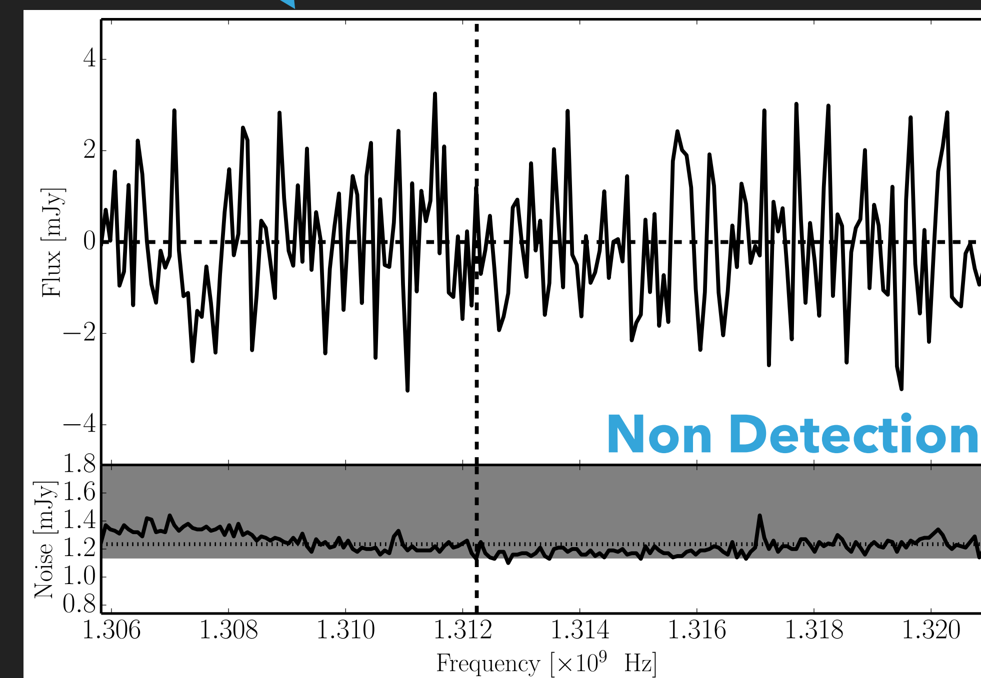
- 27%±5.5% detection rate of HI in absorption
- HI detected at all redshifts (0.02 < z < 0.23) and radio powers:
  - promising for SHARP, MALS, FLASH
- Narrow lines
    - HI mainly in a rotating disk
  - $P_{1.4GHz} < 10^{24}$ W Hz^{-1}, Extended sources, dust poor sources
- Broad asymmetric shifted lines:
    - HI has unsettled kinematics
  - $P_{1.4GHz} > 10^{24}$ W Hz^{-1}, Compact sources (i.e. often young AGN), MIR bright sources
- Stacking experiments:
  - low optical depth HI is present in the centre of ETGs, warmer HI (T_{spin} >100 K)?

BLIND SURVEYS: AUTOMATIC SEARCH FOR HI ABSORPTION

Extract the spectra @ location of every continuum source in the FOV

Line-finder: which one?





Intervening or associated?
cross-correlation with spectral surveys

Characterisation absorption
(width, centre, asymmetry etc.
e.g. busy function)

DATABASE

Properties of radio continuum
(size, spectral index, …)

Properties of the HI lines

Stacking

cross-correlation with LOFAR fields
& other archives (SDSS, WISE)

Comparison with models

other ideas…