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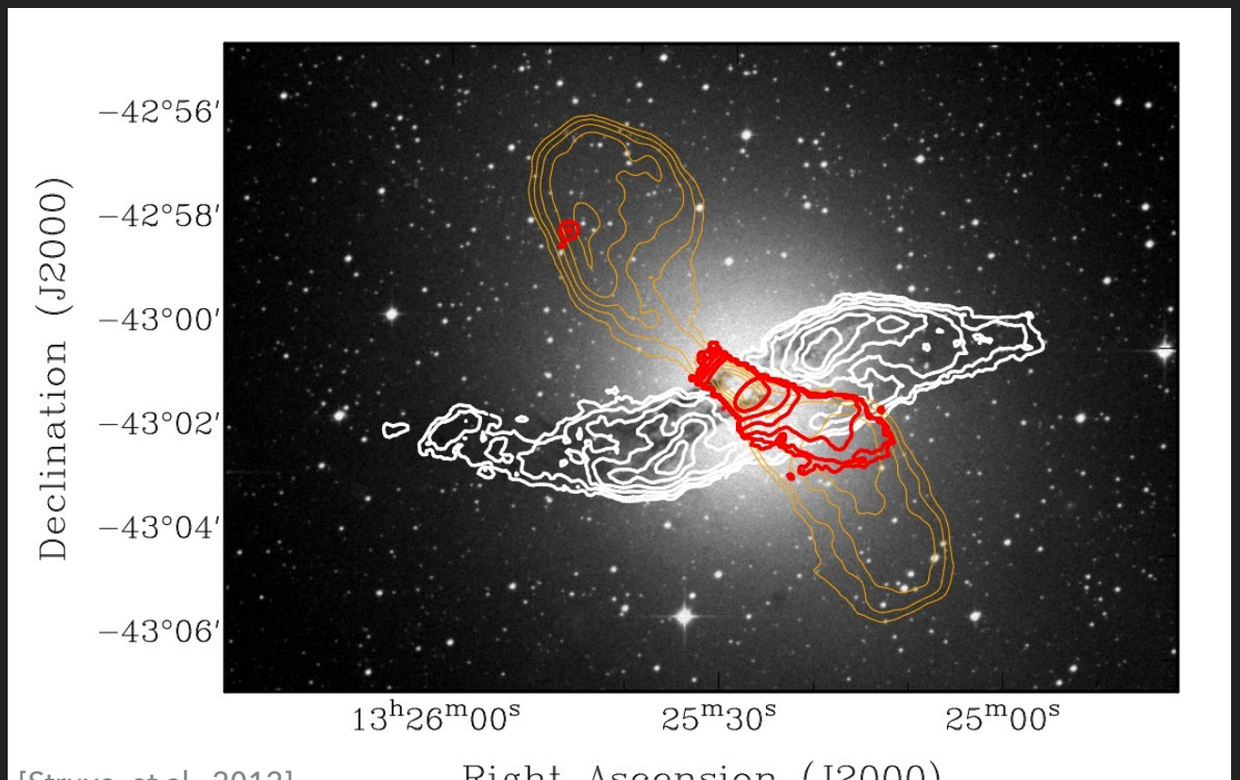
THE LAST SURVEY OF THE 'OLD' WSRT: DISCOVERING HI ABSORPTION IN LOW POWER RADIO SOURCES

ASSOCIATED HI ABSORPTION

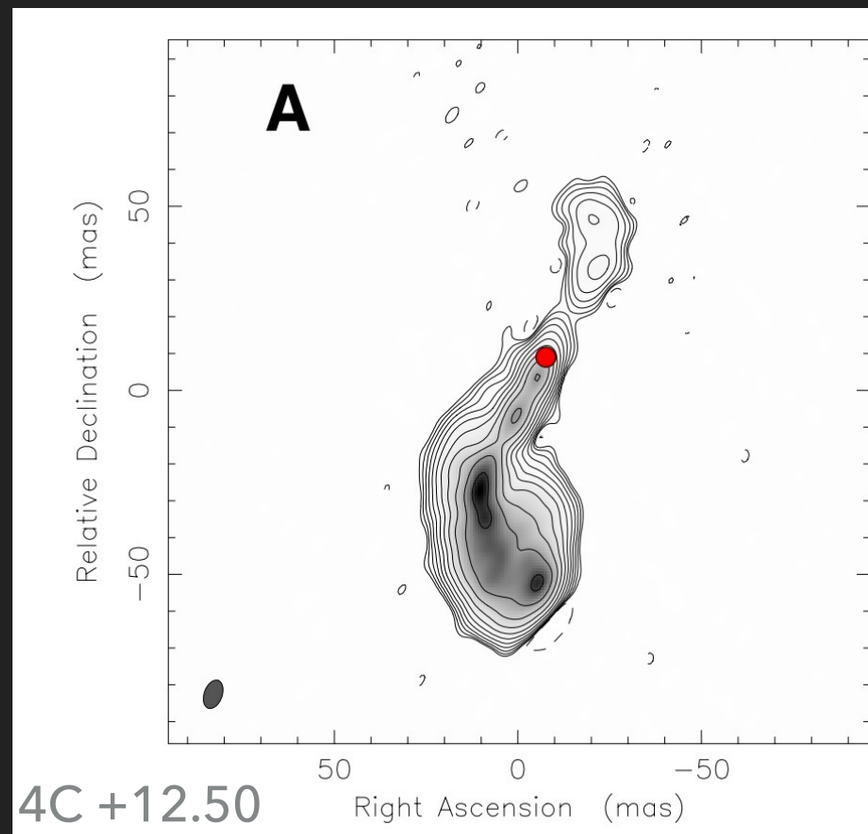
- ~ 40% of early-type galaxies have HI: ATLAS^{3D} [Serra et. al 2012]
- Early-type galaxies are the typical host of a radio-AGN.
- In radio-AGN is possible to detect HI in absorption against the radio continuum.
- Detection of absorption is independent of redshift (if the background continuum is strong enough).
- HI absorption studies can be carried out in a shallow survey, with a few hours of exposure time per object.
  - Absorption allows us to study the HI content of galaxies to high redshifts (z<1).
  - **HI absorption studies are complementary to HI emission studies.**

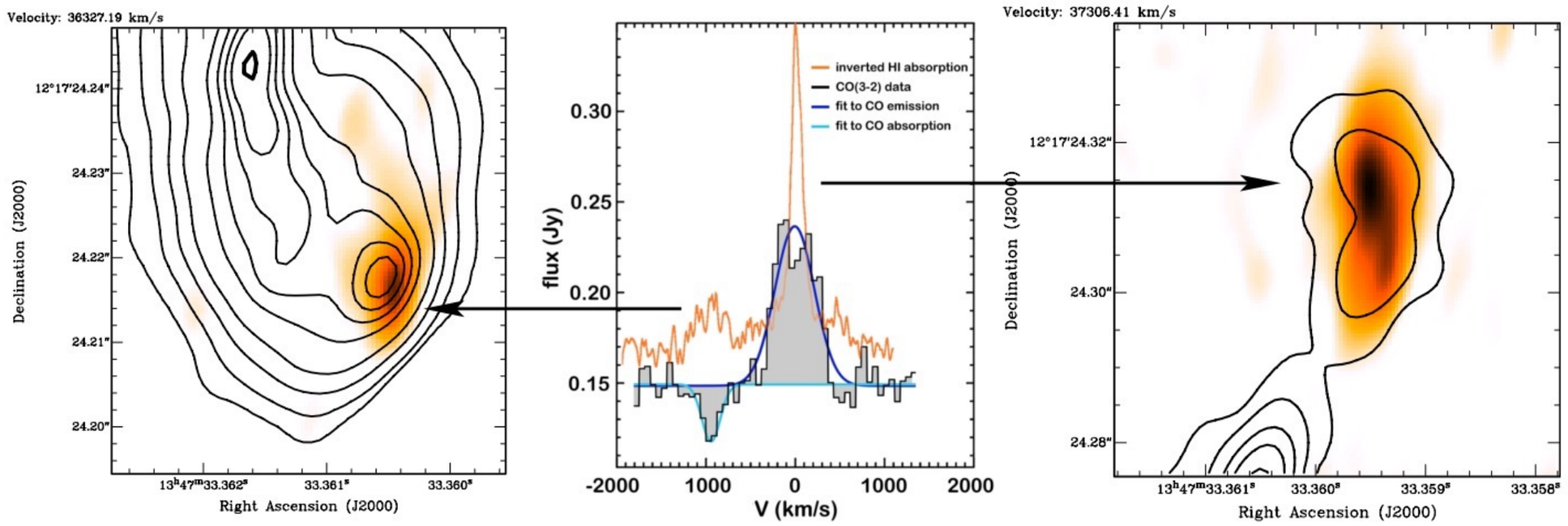


[Struve, et al., 2012]

HI ABSORPTION IN RADIO AGN

- HI absorption can trace positive feedback between the radio source and the host galaxy.
- Shallow blue shifted wings in the absorption line often trace outflows of cold gas pushed by the radio jet.
- The HI has the same kinematics as the other molecular cold gas components (e.g. CO, H2, etc).
- Study feedback between AGN and cold gas.



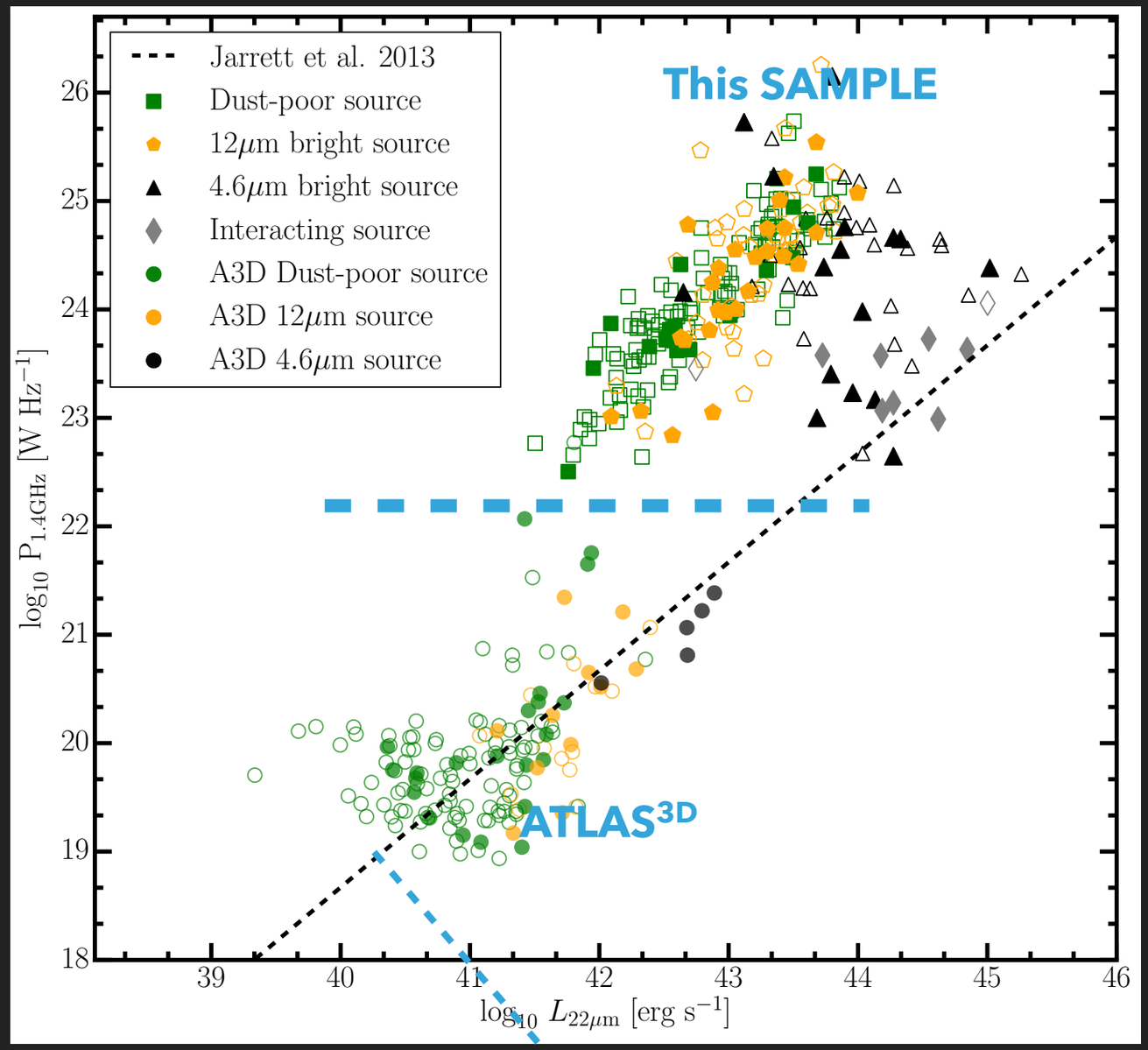


[Morganti et al. 2013]

THE LAST SURVEY OF THE OLD WESTERBORK

- 248 sources
  - 0.02 < z < 0.25
  - SDSS spectroscopy
  - $S_{Cont} \geq 30$ mJy
  - Wide range of Radio Powers
  - mostly AGN in early-type galaxies
- Two separate Data Releases:

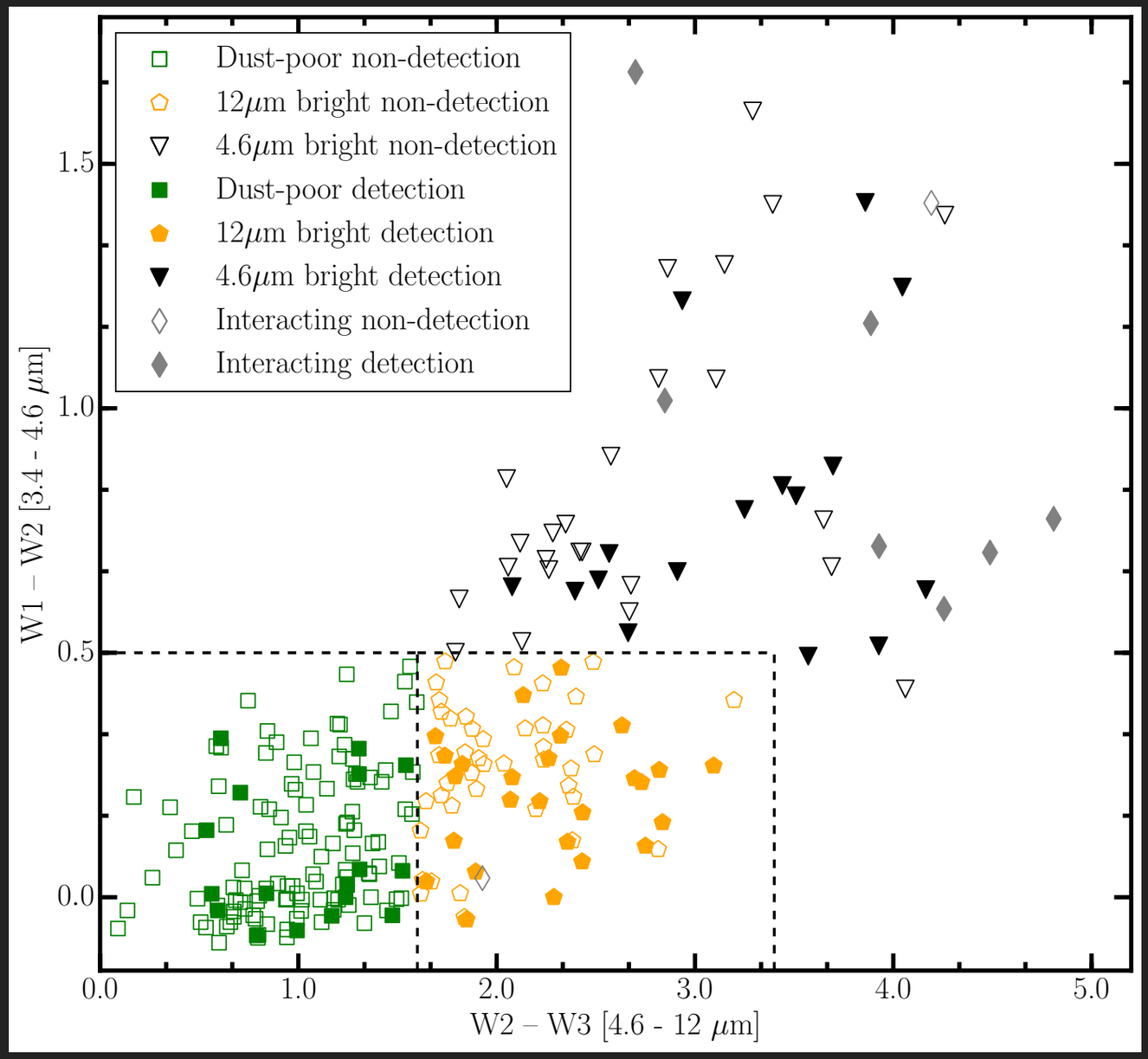
1. 101 sources; $S_{Cont} \geq 50$ mJy
   - Stacking experiment [Geréb et al., 2014]
   - Analysis of the detections [Geréb , Maccagni, et al., 2015]
2. All 248 sources
   - This Talk [Maccagni et al., submitted]



Mid-InfraRed [22 μm] - Radio Power Relation

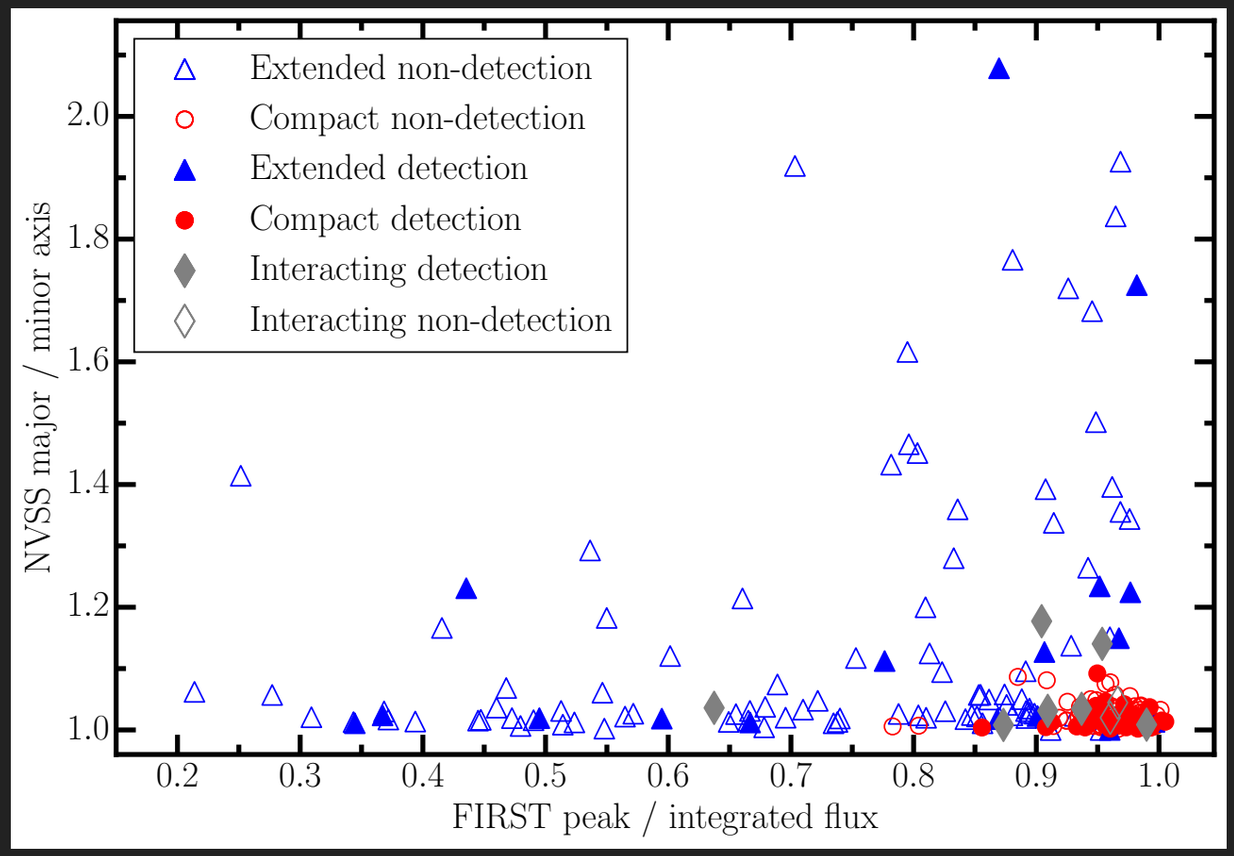
CHARACTERISATION OF THE SAMPLE

- WISE MIR colours characterise the host galaxy of the radio-AGN.
  - 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.



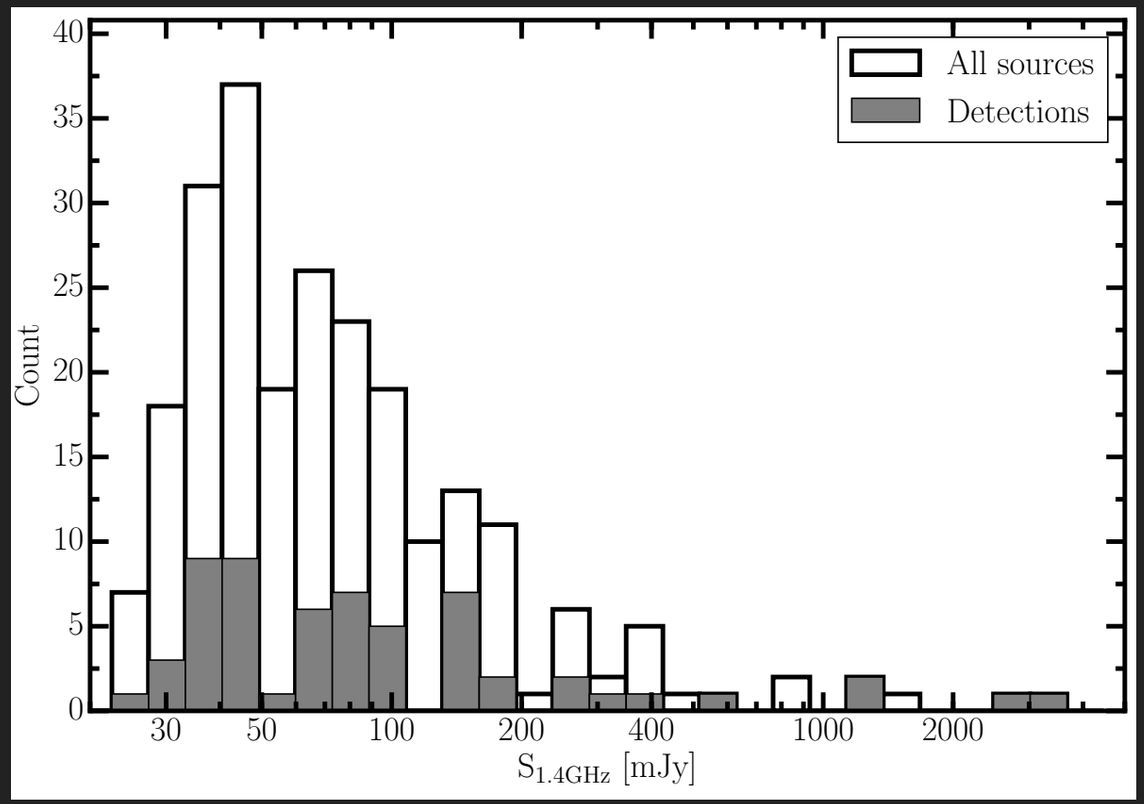
CHARACTERISATION OF THE SAMPLE

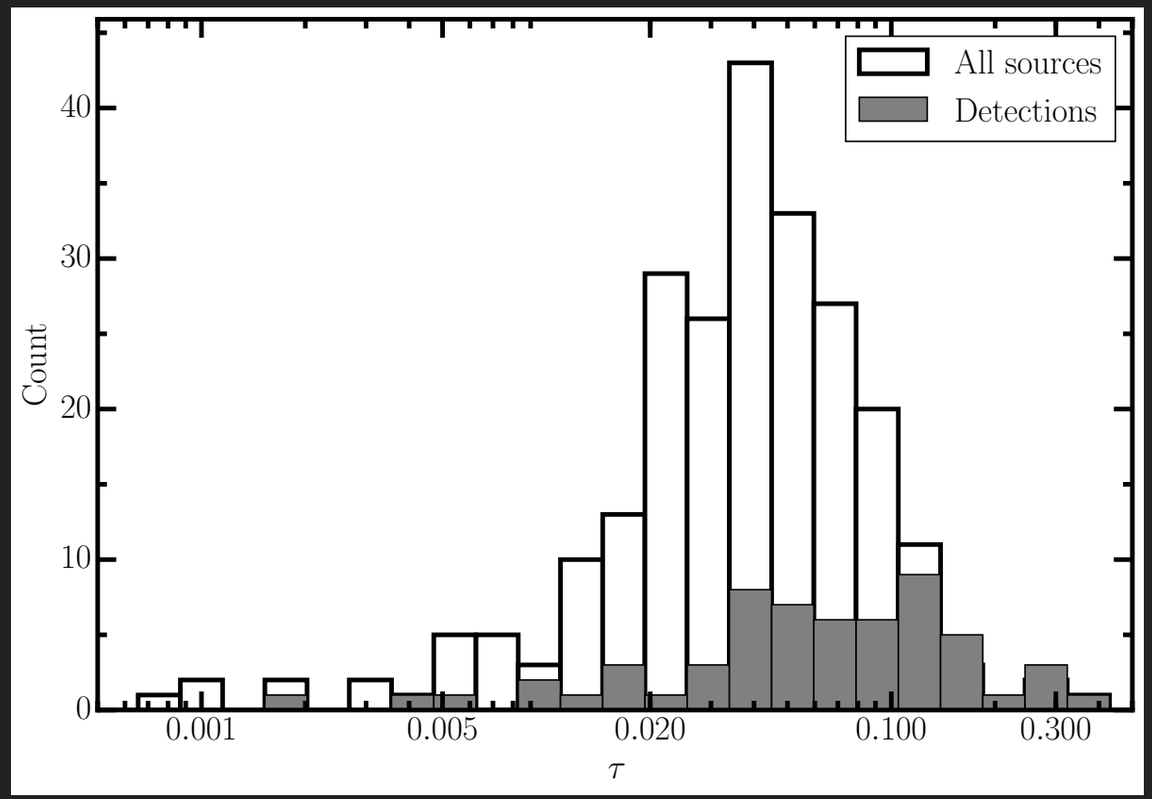
- Compact sources (red):
  - unresolved by FIRST.
  - often radio-jets on sub-galactic scales.
  - many compact sources are young AGN.
- Extended sources (blue):
  - resolved by FIRST.
  - radio-jets on super-galactic scales.
  - usually older AGN than compact sources.



DETECTING HI ABSORPTION

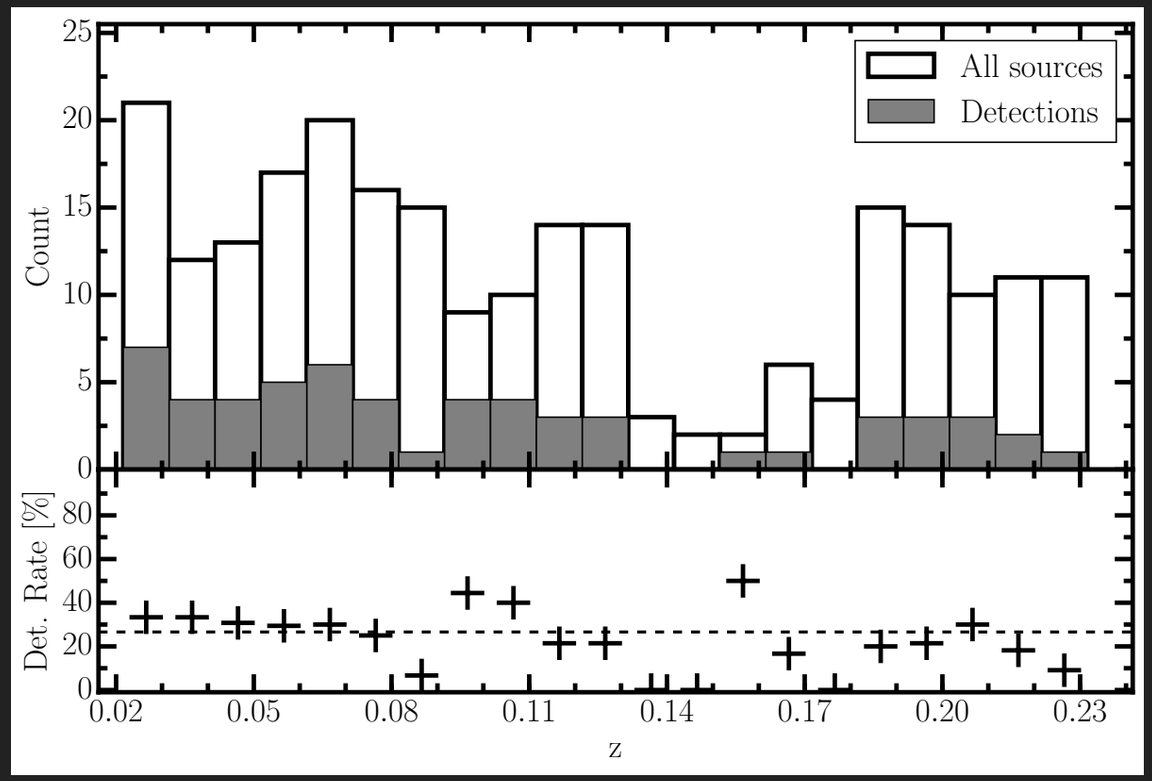
- Observe all sources with flux > 30 mJy and available SDSS spectrum.
  - Bulk of the radio population is at low fluxes [Mauch & Sadler 2007]
  - Detection of HI absorption at all redshifts.
- Shallow survey: mostly limited to high optical depths (τ~ 0.05-0.1)
- We also detect lines with very shallow peak (τ<0.007)



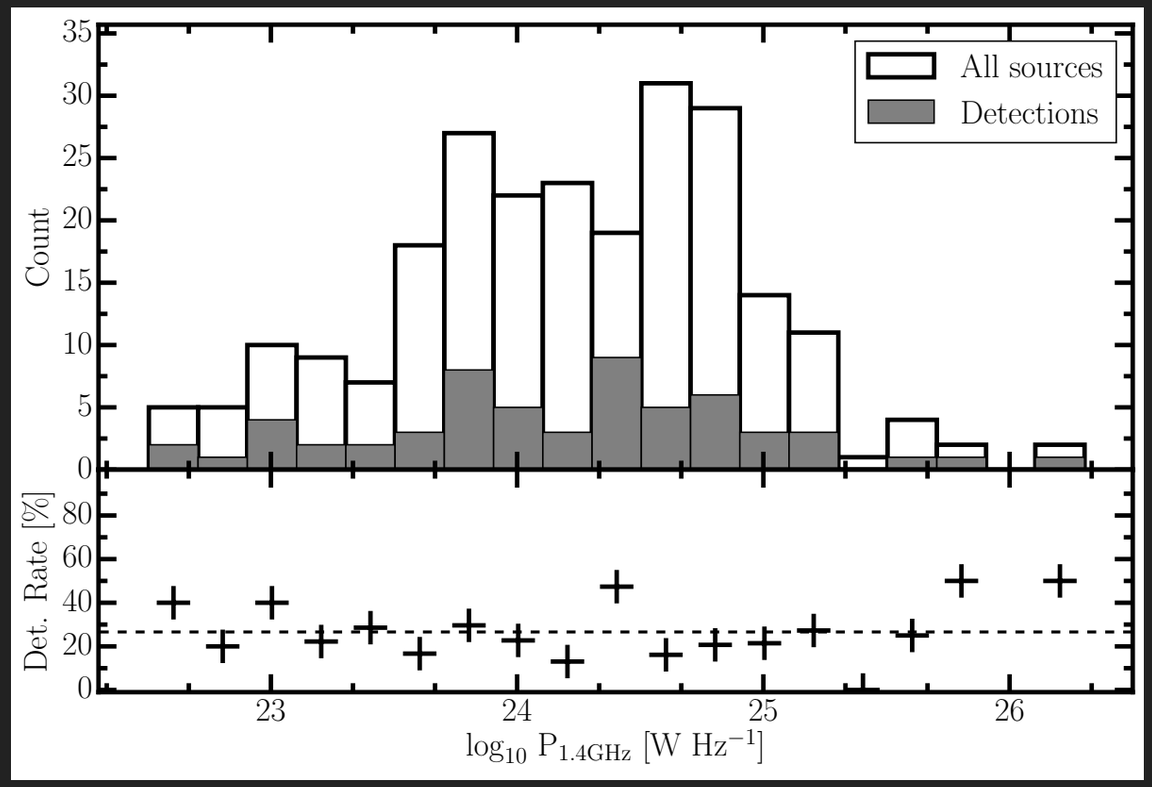


DETECTING HI ABSORPTION

- 248 sources / 66 Detections
  - **27 % ± 5.5 % detection rate**
  - We detect HI absorption at all redshifts and at all radio powers.
  - Detection of HI constant with z, and radio power.



- Compact sources, 4.6 μm-bright and 12 μm-bright
  - HI often detected (~40%).
- Extended sources & dust-poor sources
  - HI is rarely detected (~13%).



HI ABSORPTION LINES

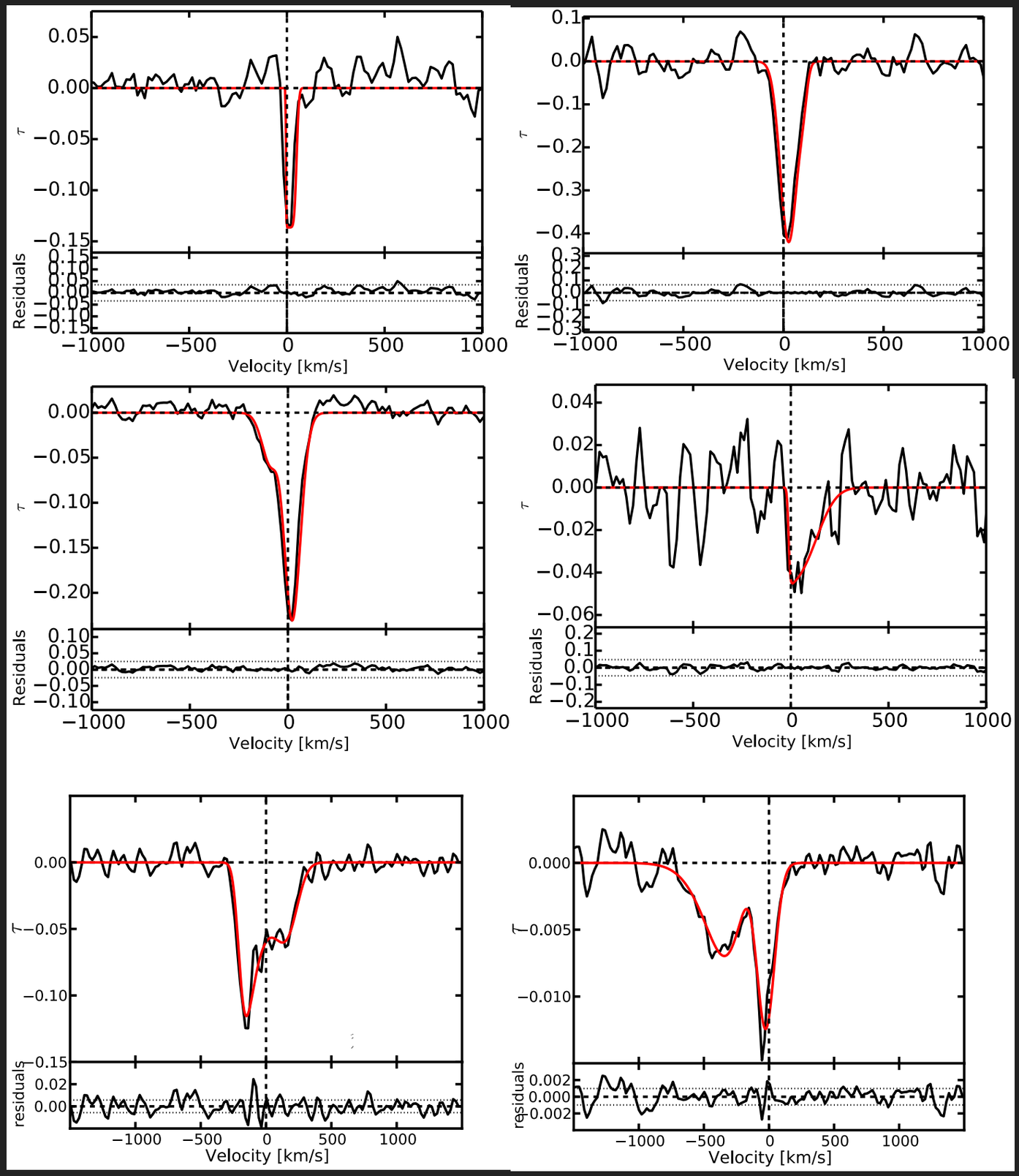
- 66 detections
- line properties measured with the BusyFunction [Westmeier, et al. 2014]
- 30 < FWHM < 570 km/s
- 70 < FW20 < 640 km/s
  - 3 main groups:
    - Narrow lines:

      FWHM < 100 km/s
    - Medium width lines:

100 km/s <FWHM < 200 < km/s

    - Broad lines:

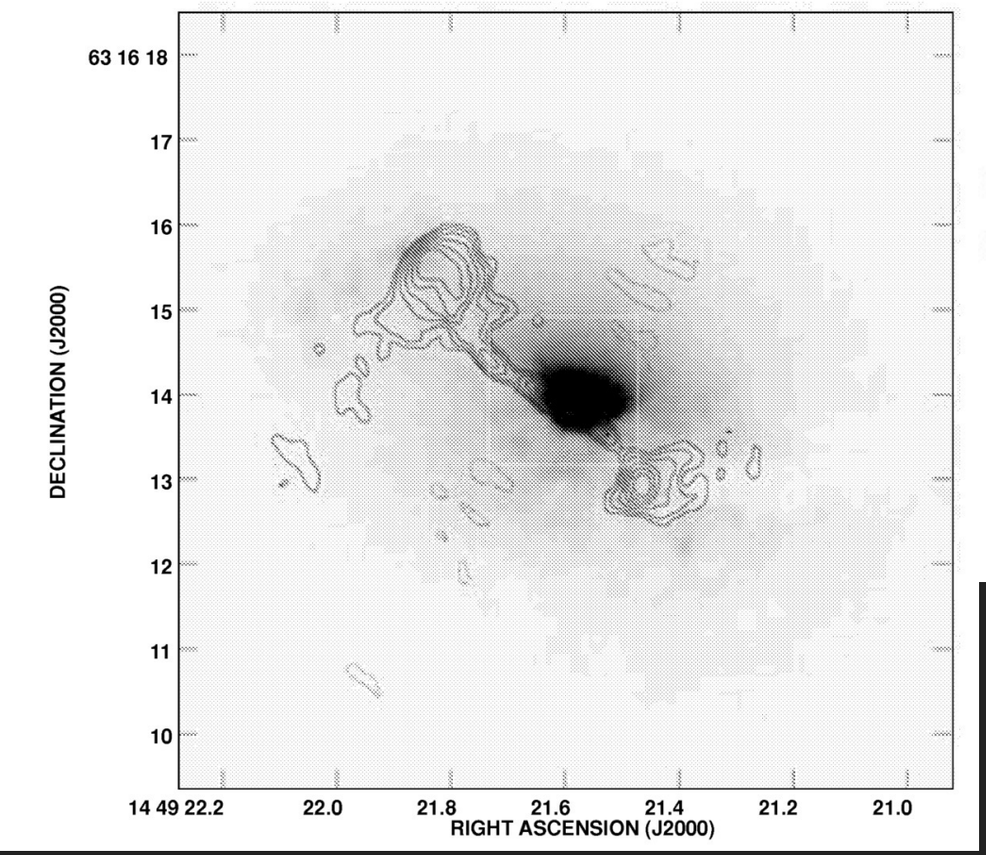
      FWHM > 200 km/s

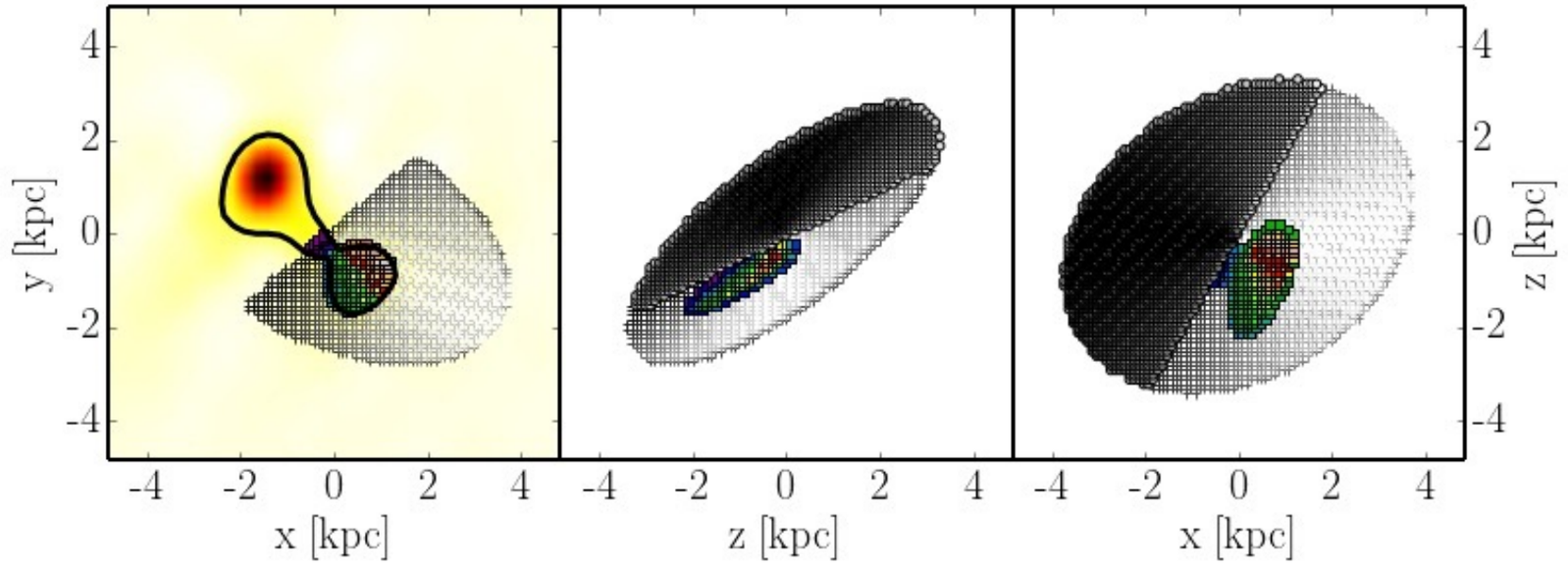


INTERPRETING HI ABSORPTION

- Understand the overall distribution of the HI traced by the absorption line
  - Narrow lines at the systemic velocity usually identify a rotating disk
  - What to can we infer from only the integrated line and the continuum image?
  - Help of a kinematical model:
    - Model the rotating HI disk in front of the radio continuum:

3C 305 Observation ⟶ Model

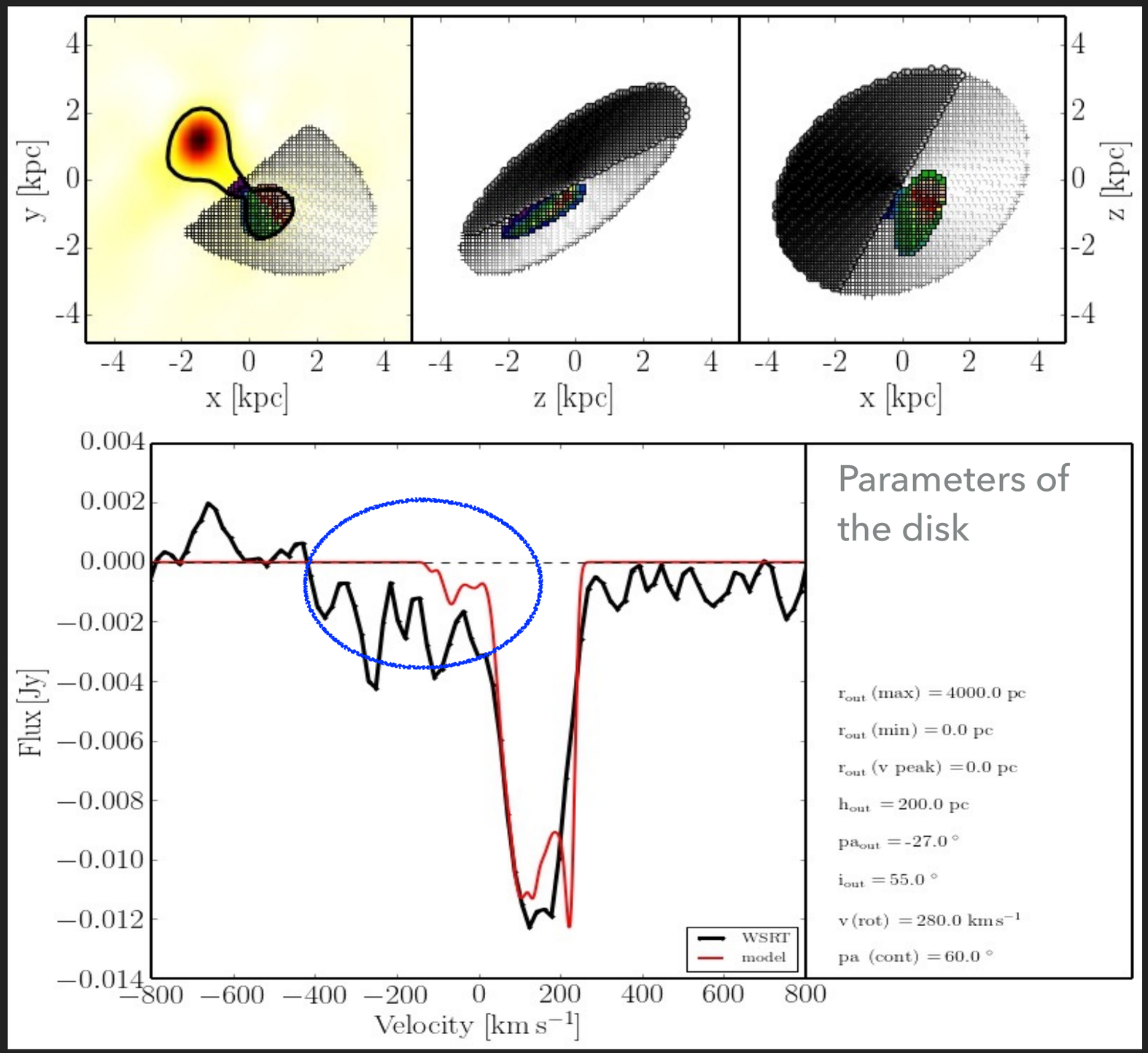




Plane of the sky : x,y Side view: z,y From above: x,z

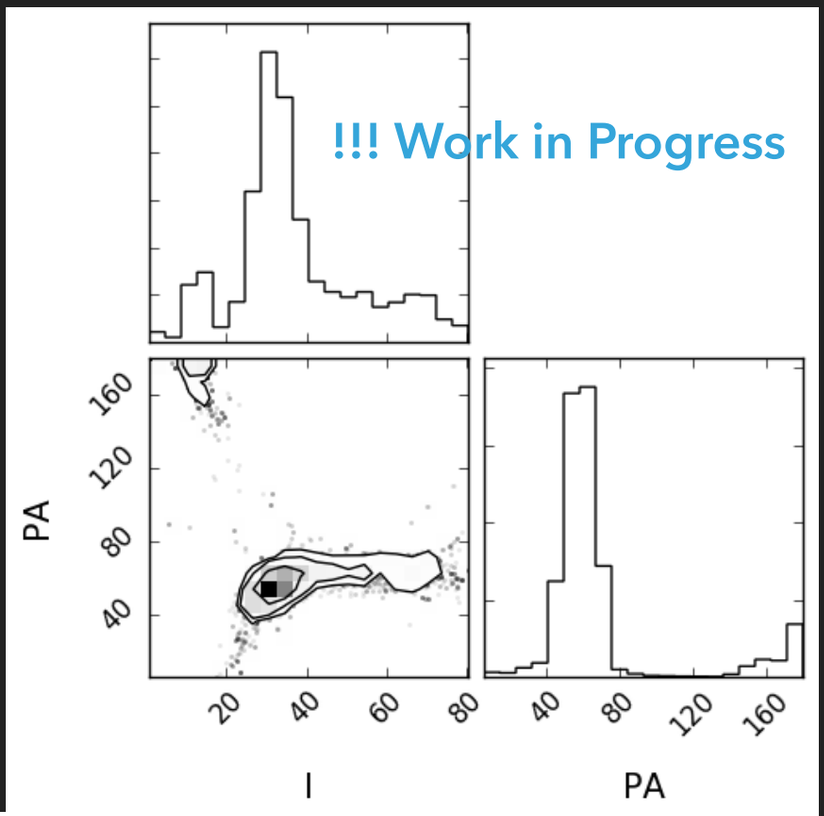
INTERPRETING HI ABSORPTION

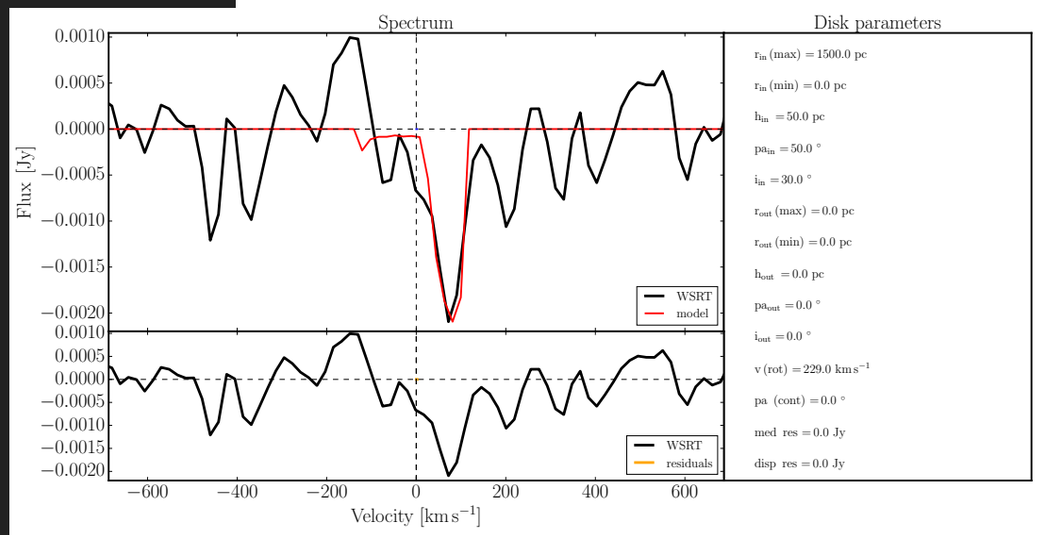
- We fix the parameters of the disk from available information on the galaxy:
  - Optical Image: i, PA
  - Continuum image
  - Tully Fisher -> V_{flat}
- We find which disk best reproduces the line
  - The bulk of the absorption is well reproduced by a rotating disk
  - Blue-shifted wing not reproduced by the model

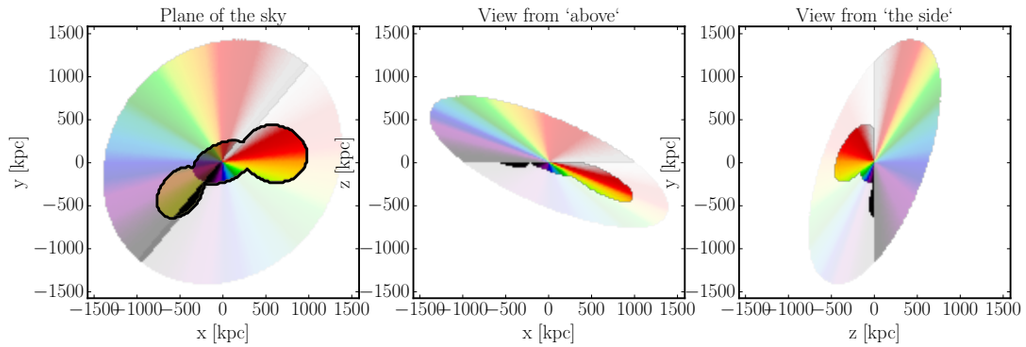


INTERPRETING HI ABSORPTION

- MCMC wrap: investigate the parameter space of I & PA automatically
  - find which combination best reproduces the line
- Future applications:
  - can we reproduce the observed distributions of properties of the lines (e.g. FWHM , tau) by simulating 10^N disks?
  - investigate the degeneracy between parameters of the disk.
  - understand when orientation effects between the host galaxy and the radio continuum play a role in detecting HI absorption.



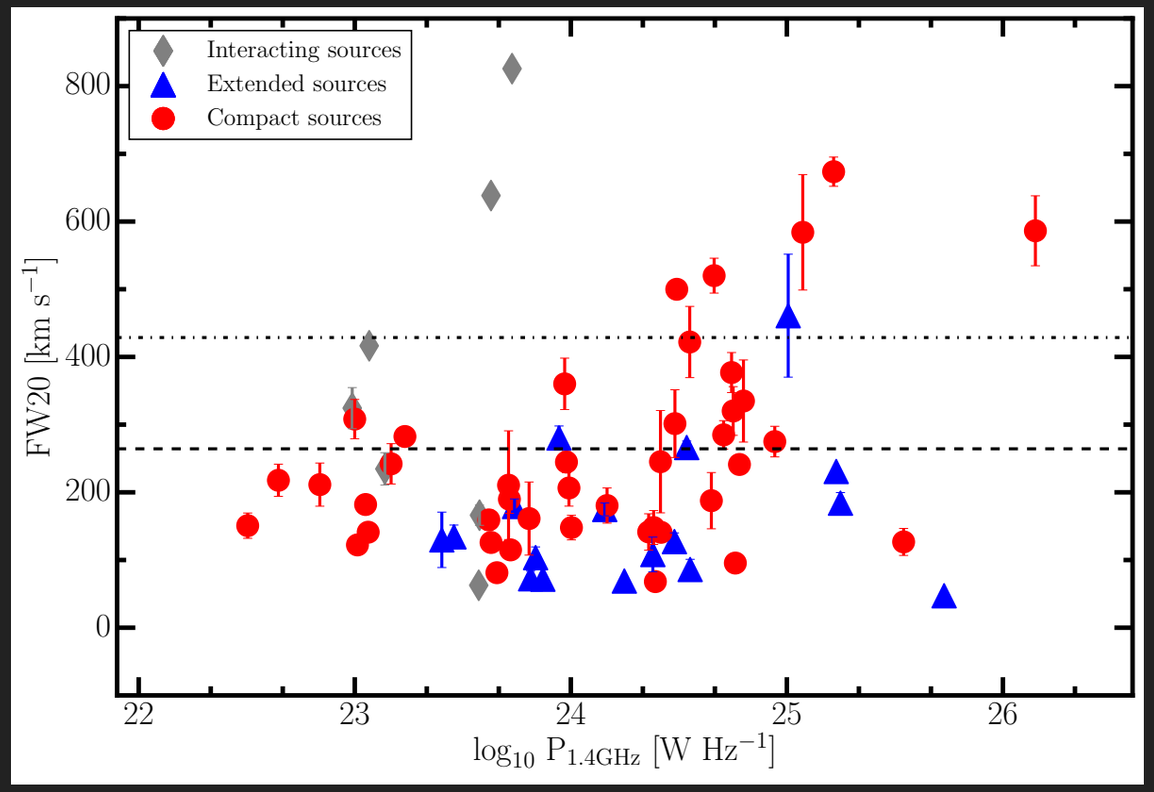


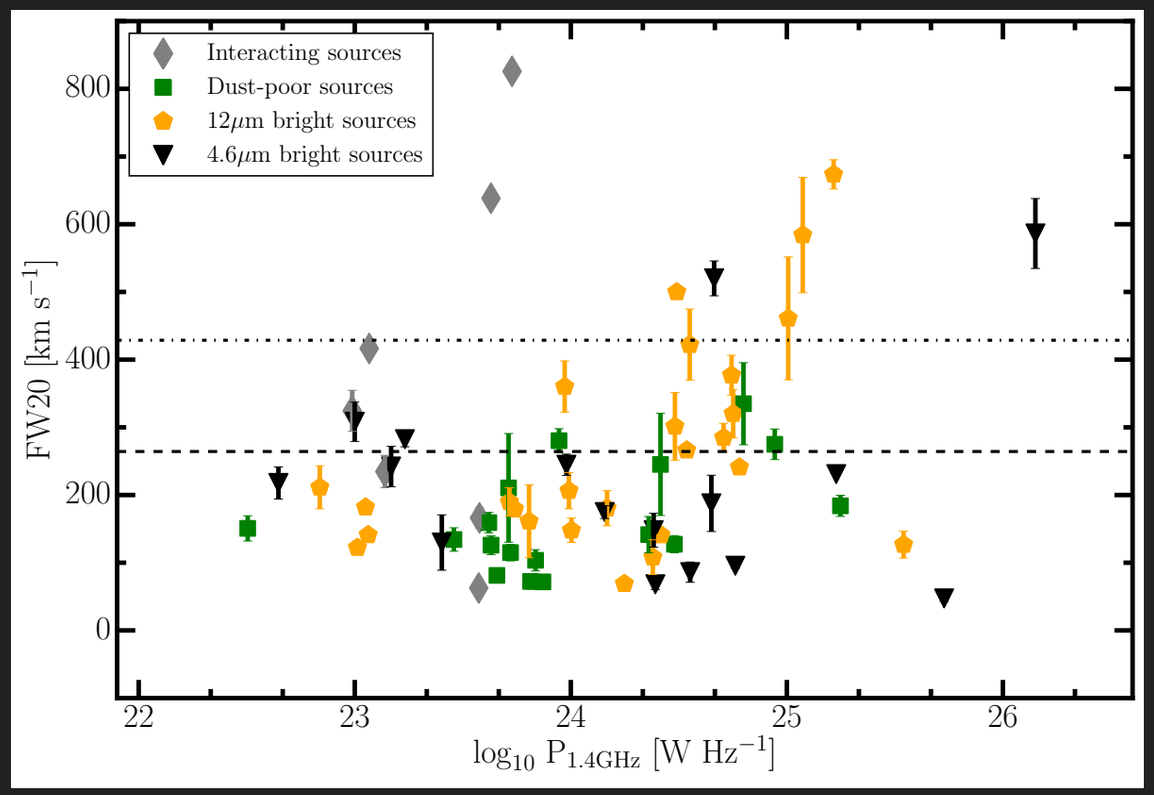


KINEMATICS OF THE HI

- $P_{1.4GHz} < 10^{24}$ W Hz^{-1}
  - lines have widths ≤ rotational velocity of the galaxy.
  - the HI is probably settled in a rotating disk.
- $P_{1.4GHz} > 10^{24}$ W Hz^{-1}
  - we detect broad lines.
  - the HI has unsettled kinematics.

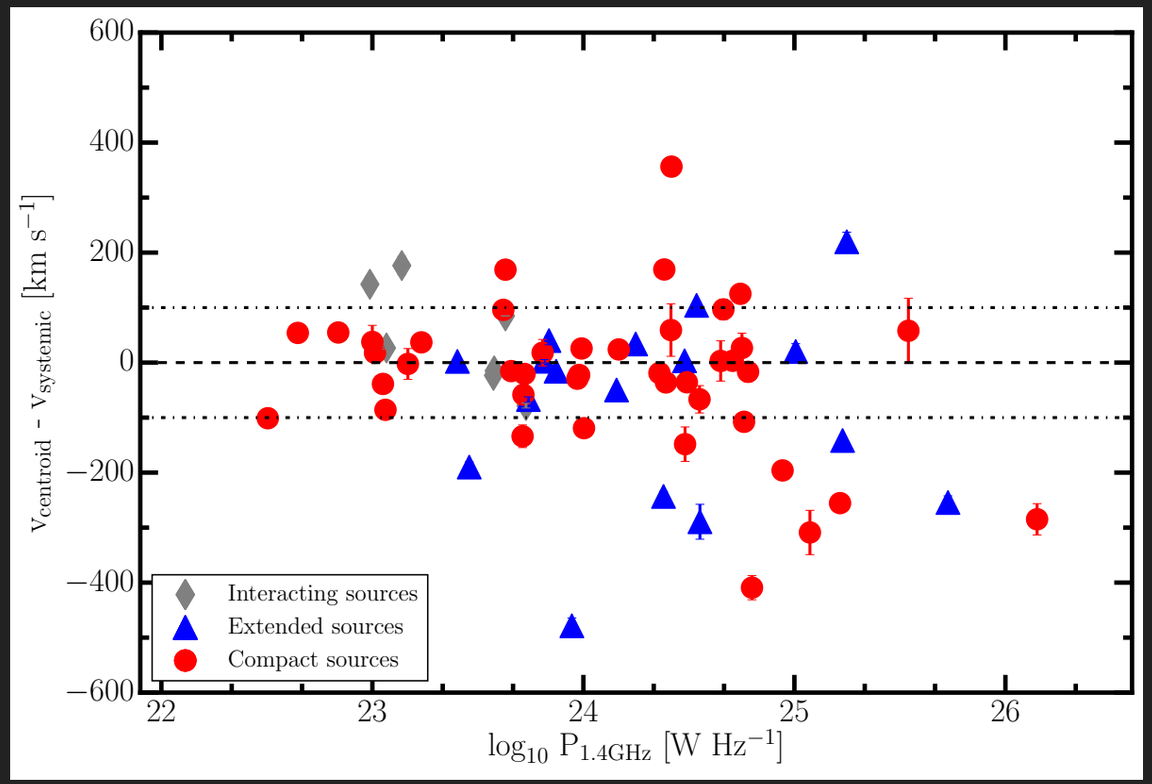
- Sources with broad lines are:
  - Compact, i.e. jets within the galaxy.
  - MIR bright, i.e. rich in heated dust.



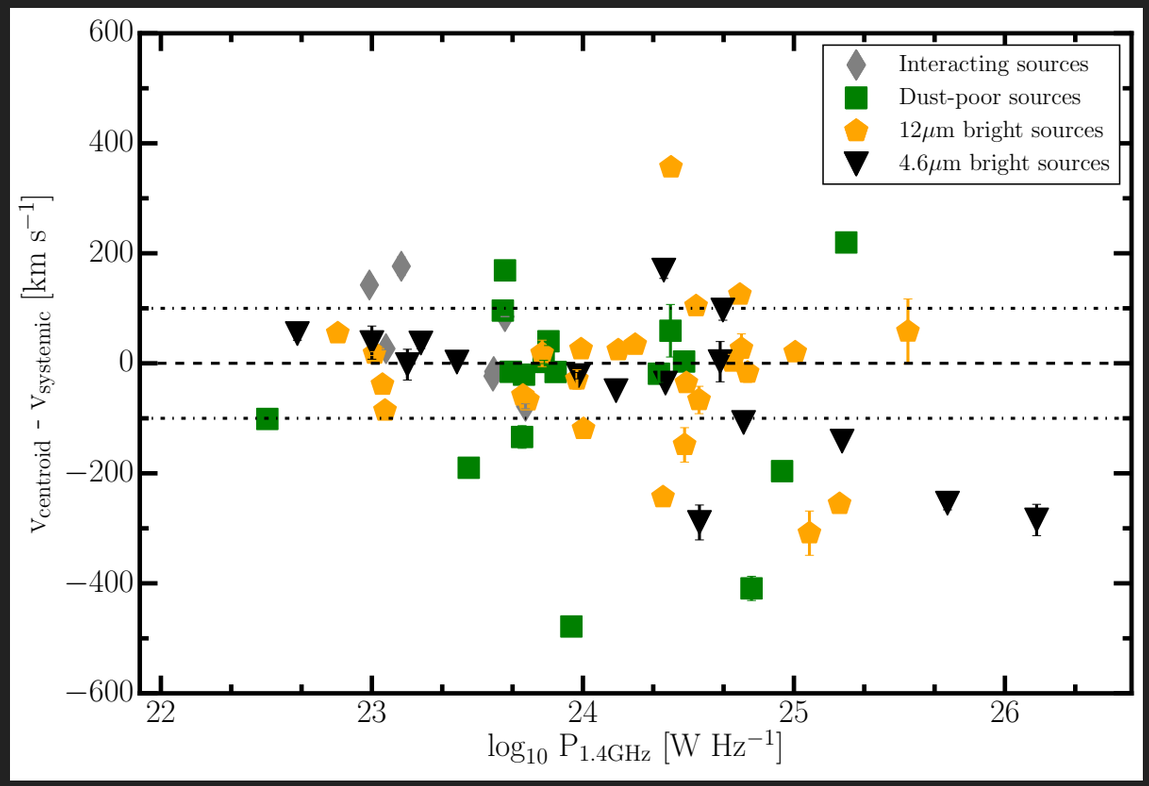


KINEMATICS OF THE HI

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

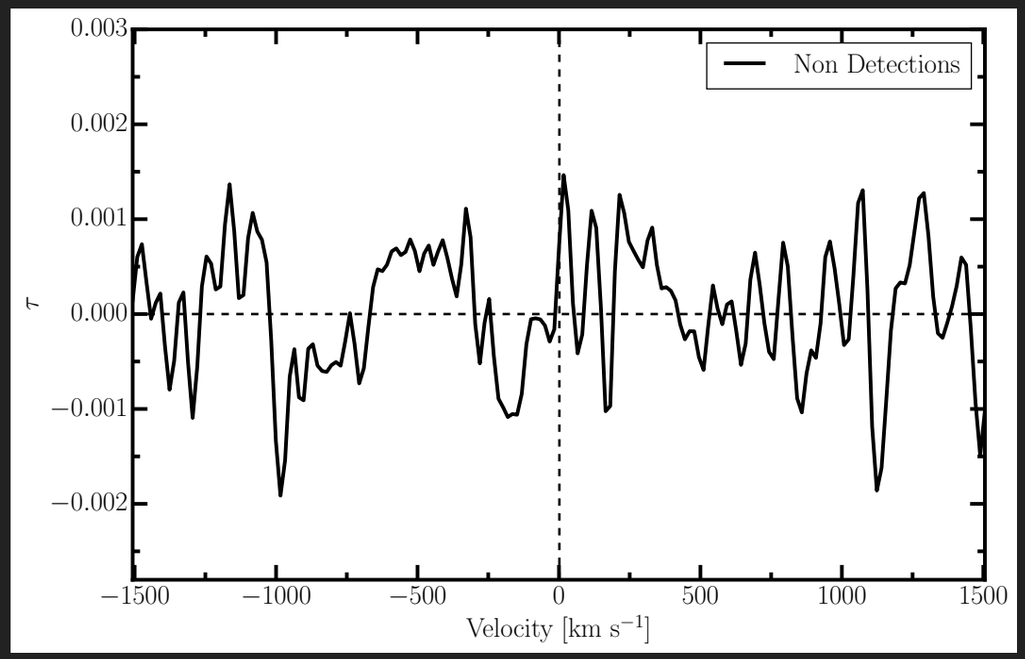


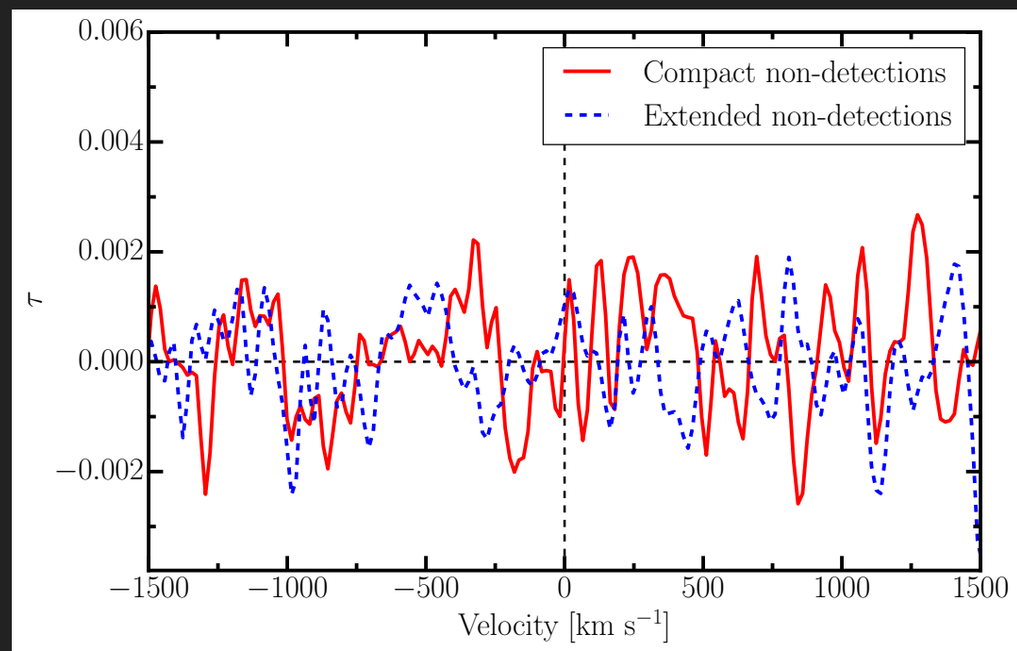
- Sources with asymmetric, shifted lines are:
  - Compact, i.e. jets within the galaxy.
  - MIR bright, i.e. rich in heated dust.
- Dust-poor sources
  - lines are narrow, mainly centred at the systemic velocity.
    - Typical signature of a rotating disk.

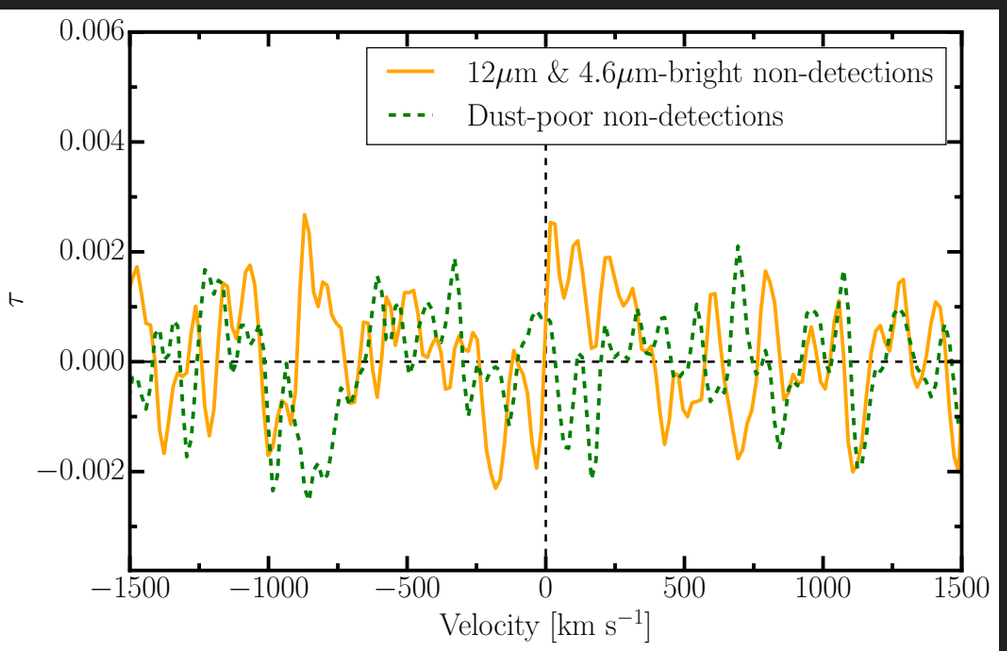


STACKING EXPERIMENT

- Non-detections are important!!!!
  - Stacking experiment to search for HI absorption at very-low optical depths.
  - 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.

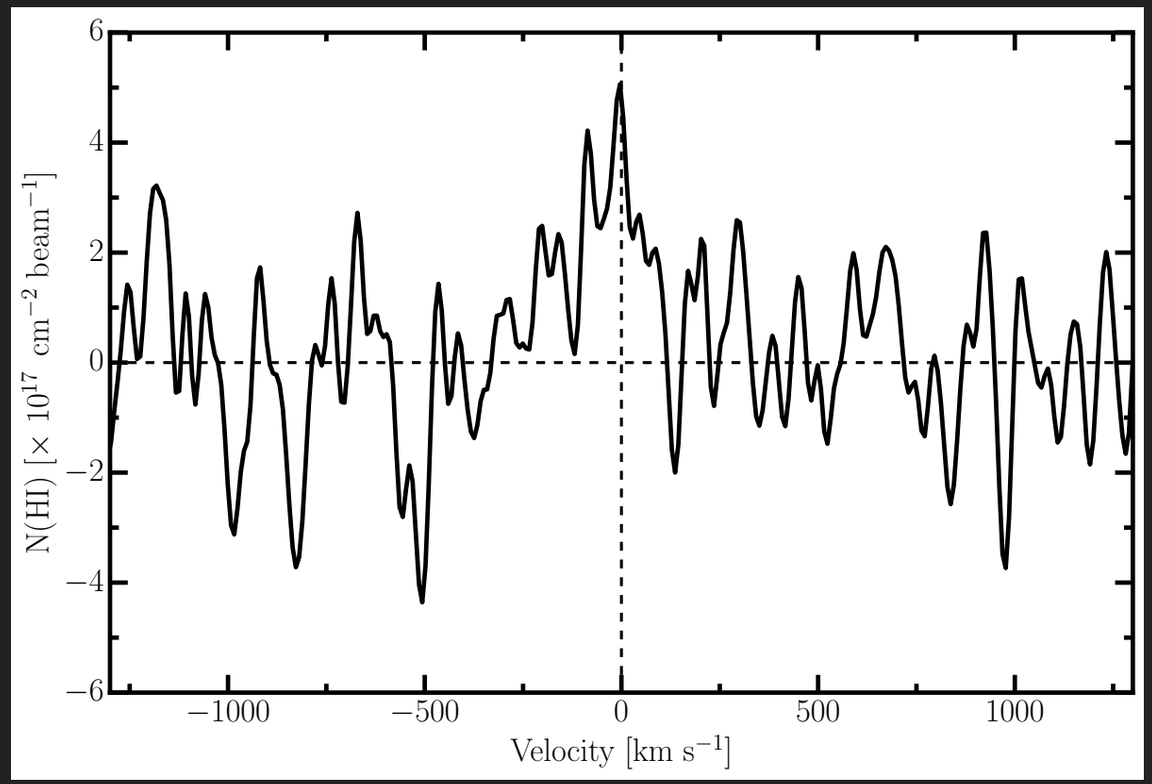






STACKING THE ATLAS^{3D} NON-DETECTIONS

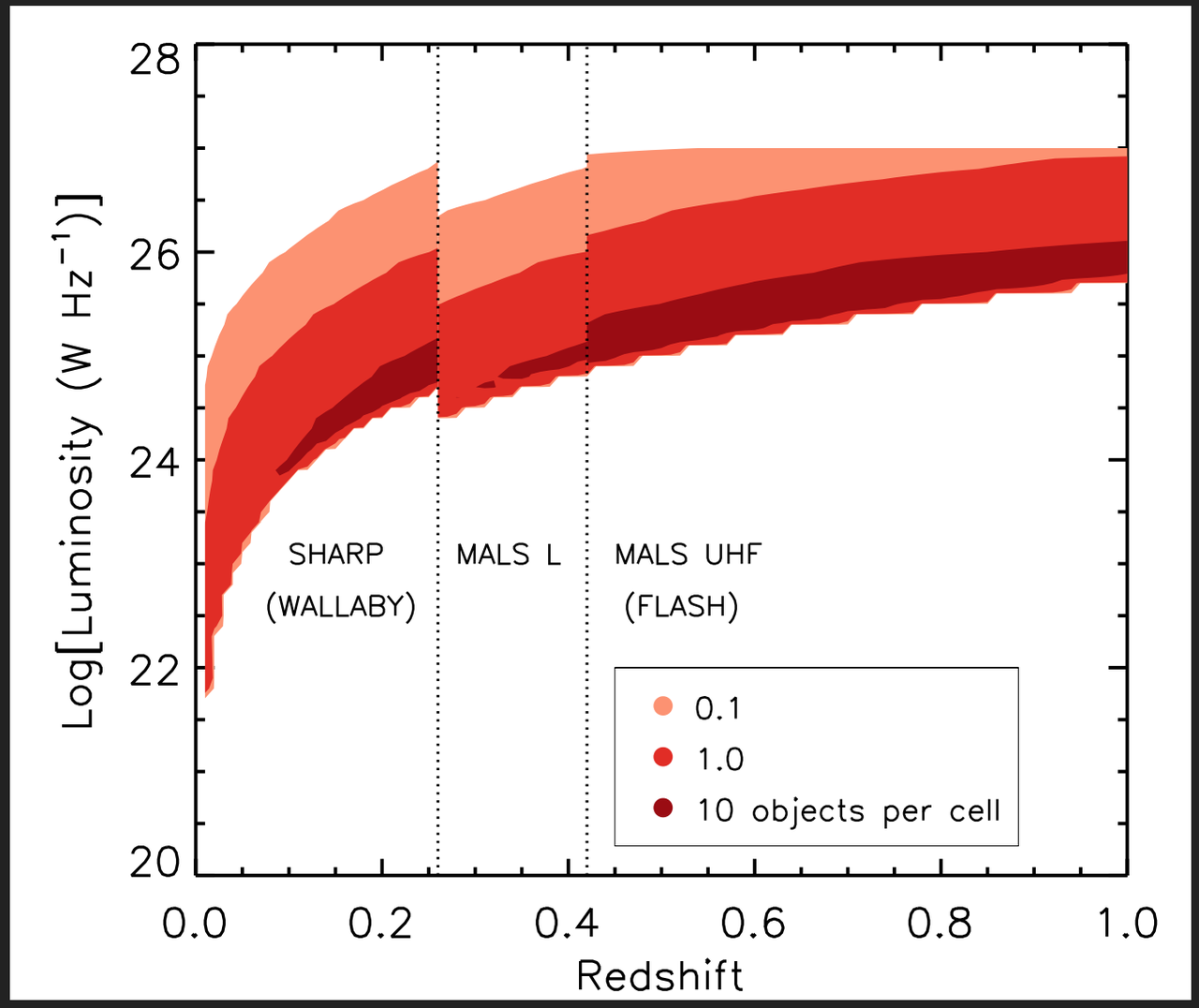
- Stacking of 81 ATLAS3D sources where the HI is non detected in the centre.
- 3σ detection of an HI emission line
  - N(HI) ~ 7.7 x 10^{18} cm^{-2}
  - On average, early-type galaxies have HI at very low column densities in the centre.



- The low column density HI we find from stacking may be present also in the stronger radio sources of our sample.
  - N(HI) converted in optical depth (T_{spin}~100 K)
    - τ~ 0.0006 << 0.0015
    - we need to stack more to detect this gas in absorption.
- N(HI) < 2x10^{20} cm^{-2} if T_{spin} > 600 K.
- **The HI we see stacking ATLAS 3D may be warm!**
- T_{spin} ↑ ⇒ τ ↓ ; T_{spin} ↓ ⇒ τ ↑
- Stacking in absorption even more difficult if T_{spin} ~ 10^3 K.

THE UPCOMING HI ABSORPTION SURVEYS

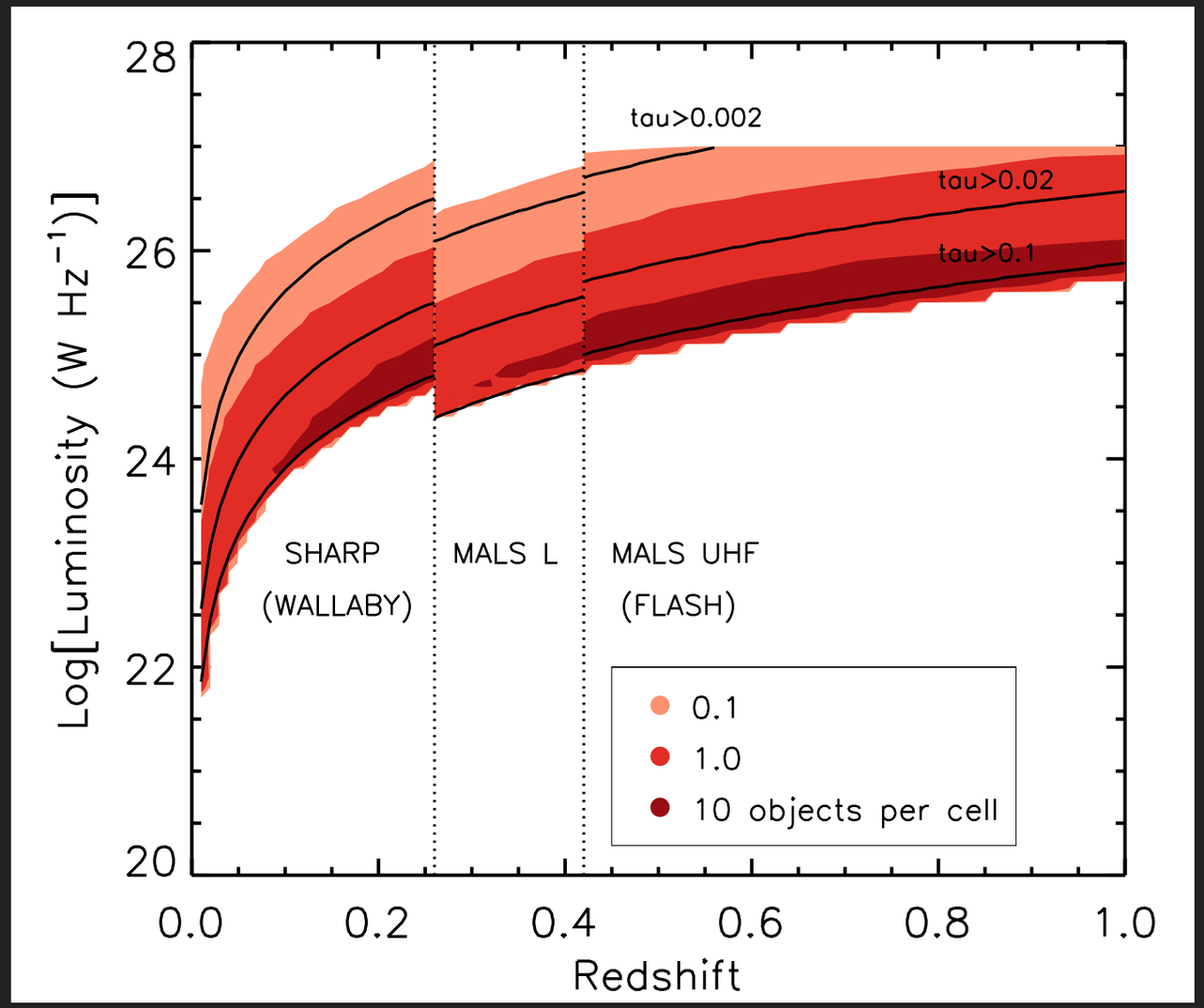
- HI absorption surveys with the SKA pathfinders and precursors
  - SHARP at Apertif
  - MALS at MeerKAT
  - FLASH at ASKAP
  - WALLABY: absorption at low redshift “for free”.
- From the continuum source population and our detection rate (27%) we predict what these surveys will detect for HI absorption



- The surveys are complementary to investigate the HI content in sources of radio power between 1022 and 1027 W Hz-1
- SHARP (and WALLABY) will allow us to detect HI absorption in low-power radio sources.

THE UPCOMING HI ABSORPTION SURVEYS

- All surveys will detect all the different kinds of HI absorption lines
  - High optical depth (>0.1)
  - Intermediate optical depth (0.02)
  - Low optical depth (> 0.002)
    - typical signatures of outflows.



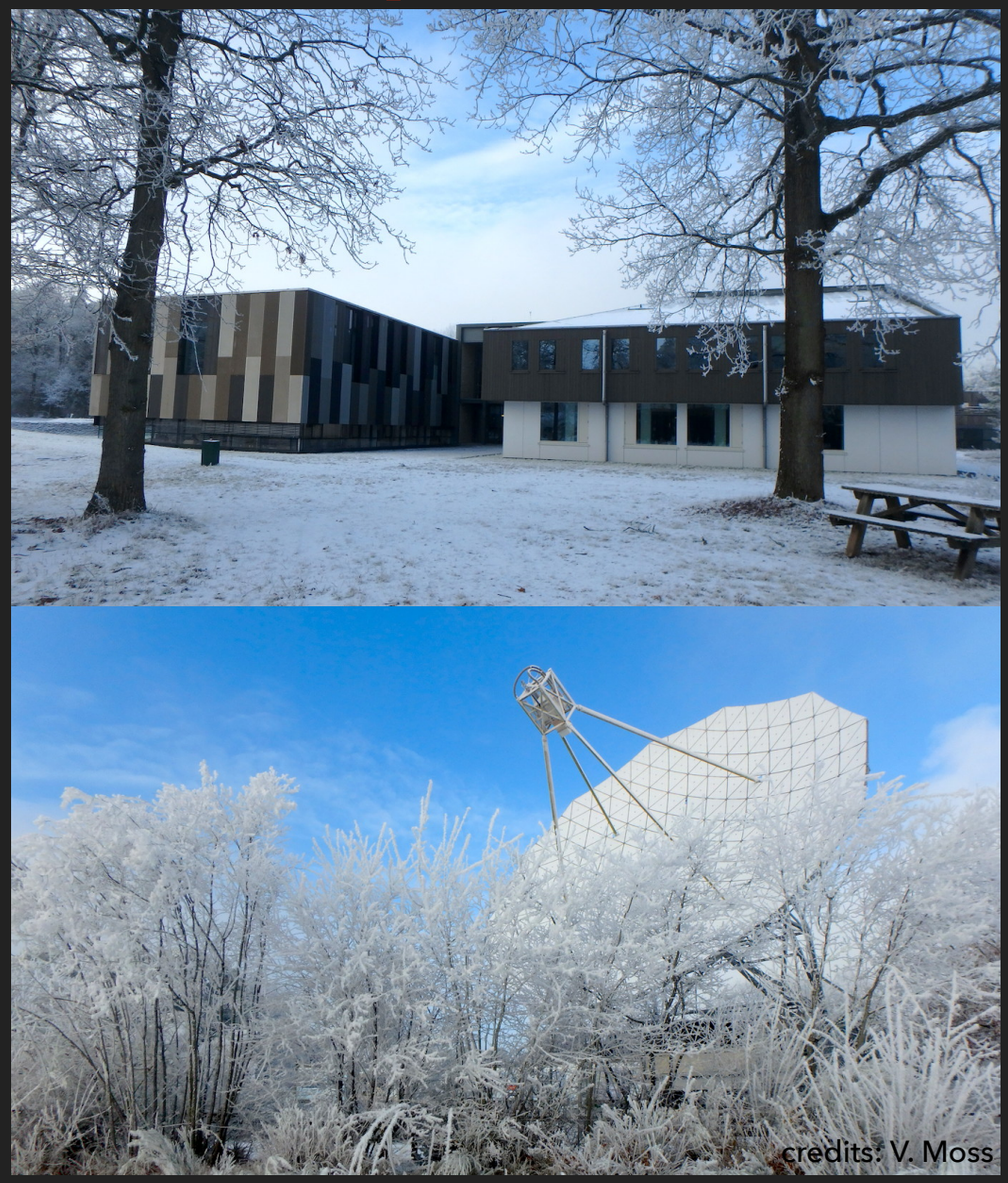
- Only SHARP and WALLABY will be able to detect low optical depth HI lines (τ > 0.002) in low power sources ($P_{1.4GHz}$ ~ 10^{24} W Hz^{-1})

CONCLUSIONS

- 27%±5.5% detection rate of HI in absorption
- HI detected at all redshifts (0.02 < z < 0.23) and radio powers
- AGN with radio power < 10^{24} W Hz^{-1} only show narrow lines. AGN with $P_{1.4GHz}$>10^{24} W Hz^{-1} show broad lines which can trace HI with unsettled kinematics
- Broad lines are found in compact, i.e. often young, radio AGN, and in MIR-bright sources.
- Dust poor sources only show narrow lines.
- Stacking experiment suggests a low optical depth HI component is present in the centre of non-detections. This gas may be warmer than the one detected by single observations.
- Upcoming HI absorption surveys are complementary. We will be able to investigate the HI content in radio sources of all radio powers (10^{22} - 10^{26} W Hz^{-1}), out to z~1.

ADVERTISEMENT

- **HI absorption with the new radio telescopes**
- WORKSHOP at ASTRON
- 14 -16 June 2017
  - status of the telescopes and data available for early science;
  - planning for HI absorption surveys;
  - experience built in the last years and tools available for the handling and analysis of new data;
  - follow-up and ancillary data: molecular gas, optical identifications, high resolution radio data;
  - requirements and possibilities for comparison with numerical simulations.



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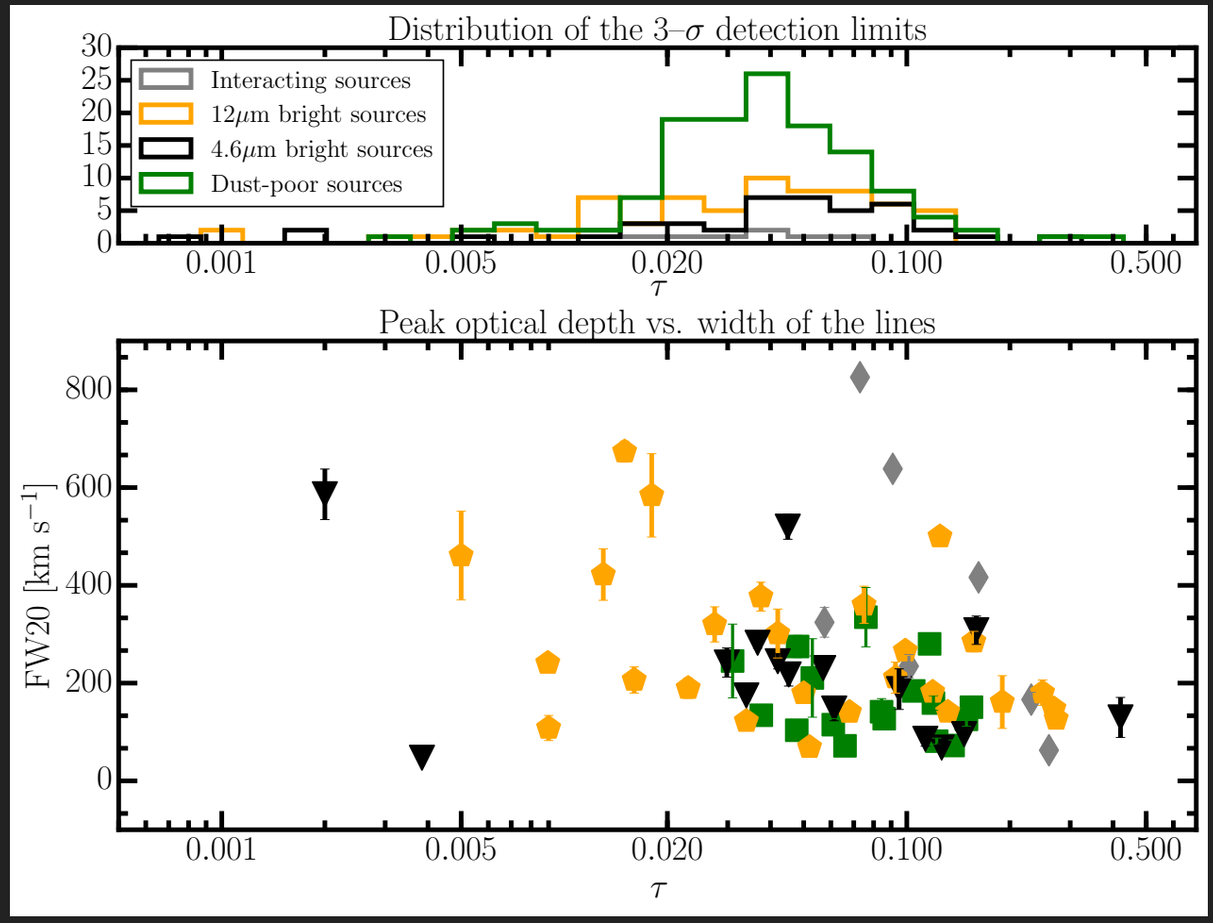
Elaine Sadler
Tom Oosterloo
James Allison
Neeraj Gupta

KINEMATICS OF THE HI

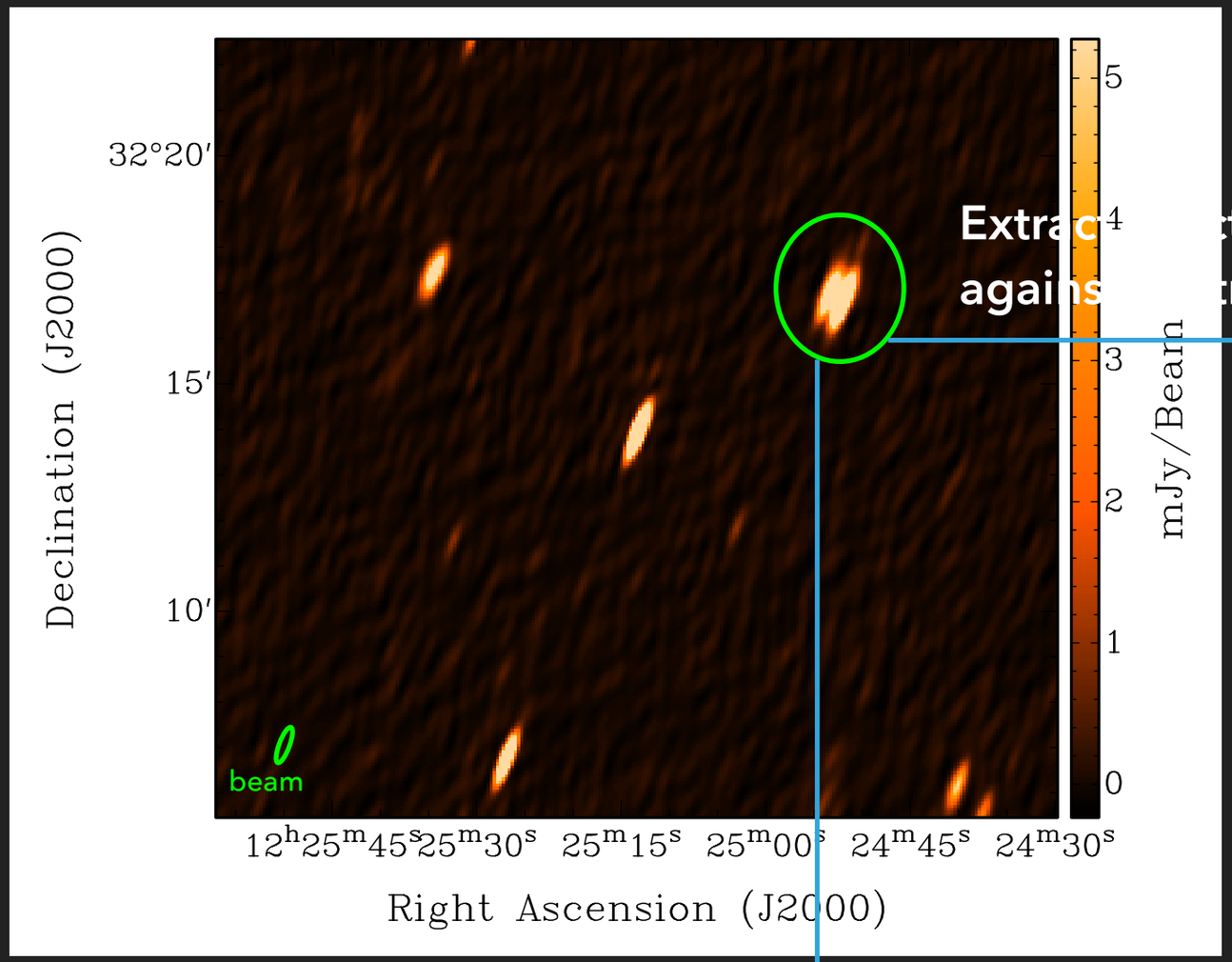
- **Dust-poor sources**
  - lines are narrow.
  - lines have high optical depth.
    - Typical signature of a rotating disk.
- **MIR bright sources**
  - lines can be shallow and broad, if $P_{1.4GHz} > 10^{24}$ W Hz^{-1}
  - lines can also be asymmetric because they have a blue-shifted wing

- In powerful radio sources the jets may unsettle the HI.
  - via outflows pushed by the radio jets
  - ⇒ blue shifted wing in the absorption line



SURVEY STRATEGY

- 247 observations pointed at the radio source:
  - Radio continuum + data cube



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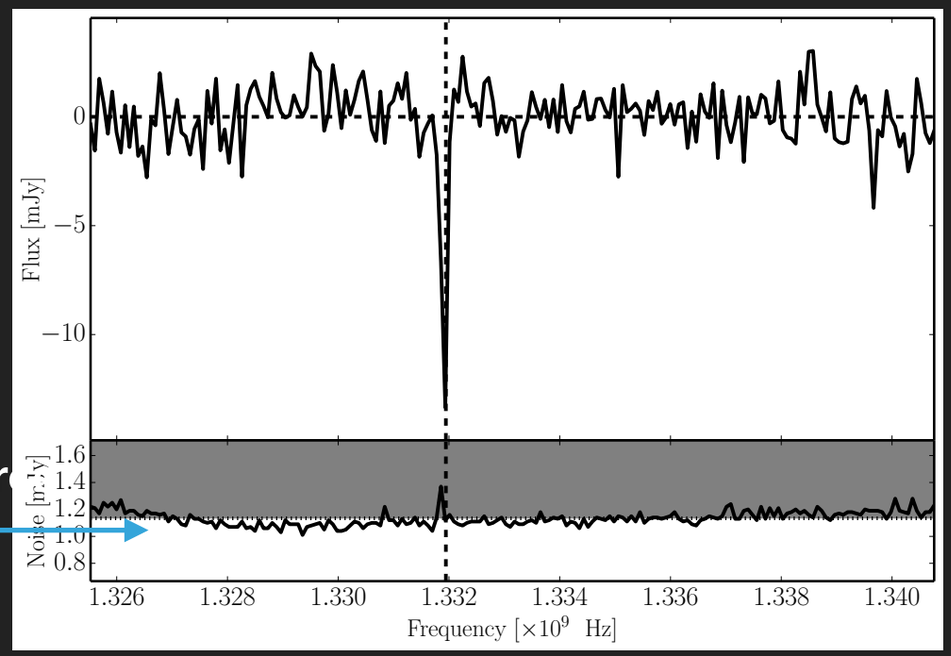
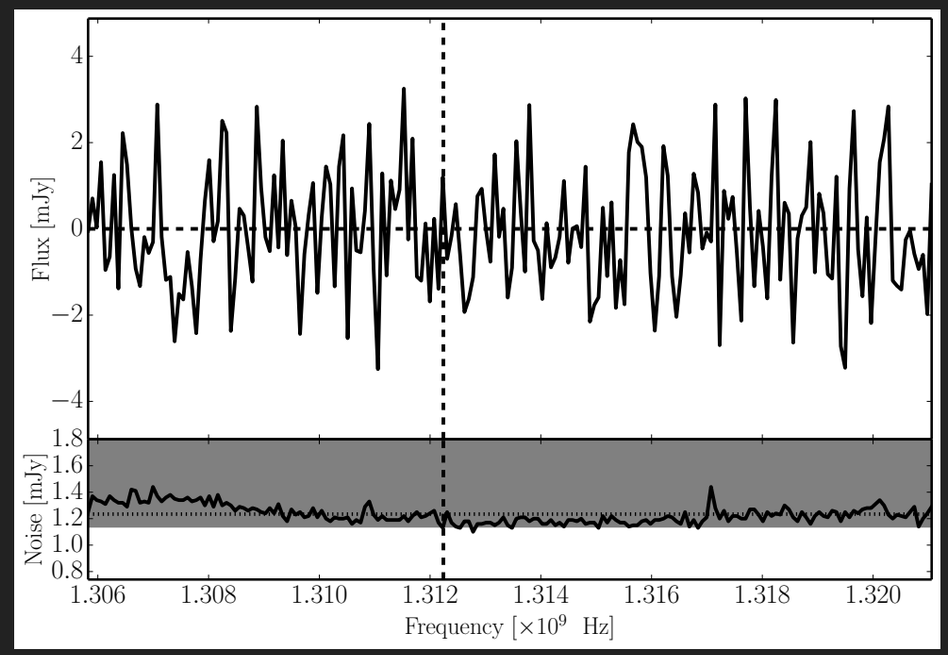
Detection



Non Detection



- 1 serendipitous detection of a field source
  - promising result for the upcoming Apertif-Sharp and ASKAP-FLASH surveys, which will search for HI absorption in every source of the field.