PARSEC-SCALE HI ABSORPTION STRUCTURE IN A LOW-REDSHIFT DLA GALAXY

ANDY BIGGS **ESO**
MARTIN ZWAAN **ESO**
EVANTHIA HATZIMINAOGLOU **ESO**
CELINE PÉROUX **MARSEILLE/ESO**
JOE LISKE **HAMBURG**

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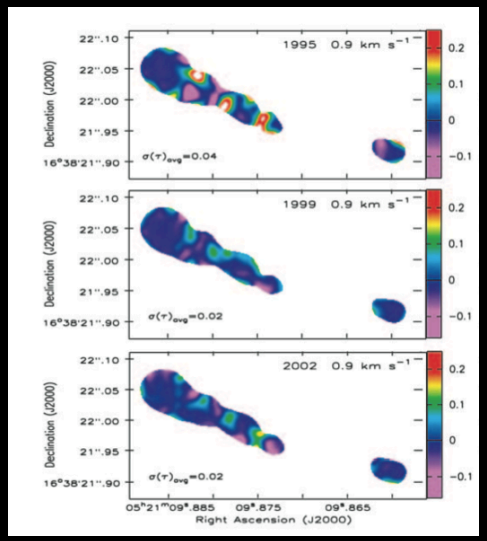
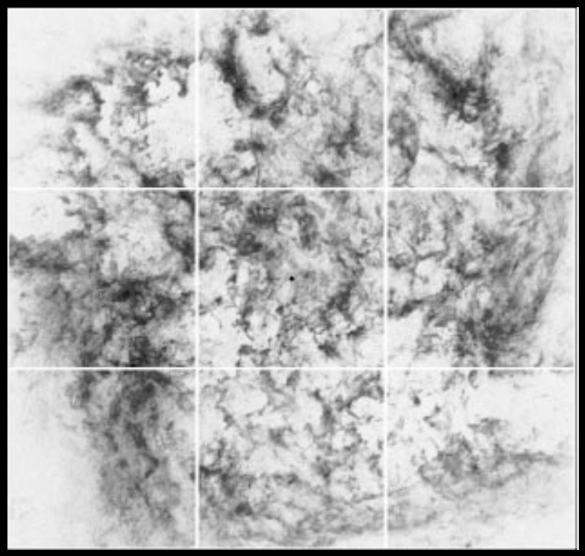
SMALL SCALE STRUCTURE IN ISM

- Why
  - Structure and turbulence of the neutral medium determine size distribution of molecular clouds and affects the shape of the stellar IMF
  - Understand HI absorbers at higher redshifts
- How
  - Galactic HI absorption probes scales down to several AU e.g. 3C138
  - Emission studies typically probe scales > 100 pc
  - HI VLBI absorption in external galaxies probes parsec-scale structure

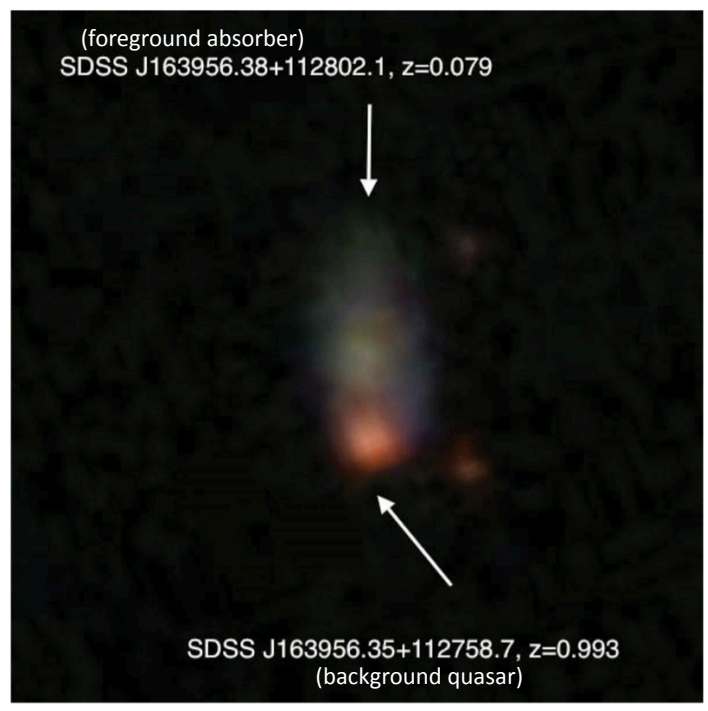


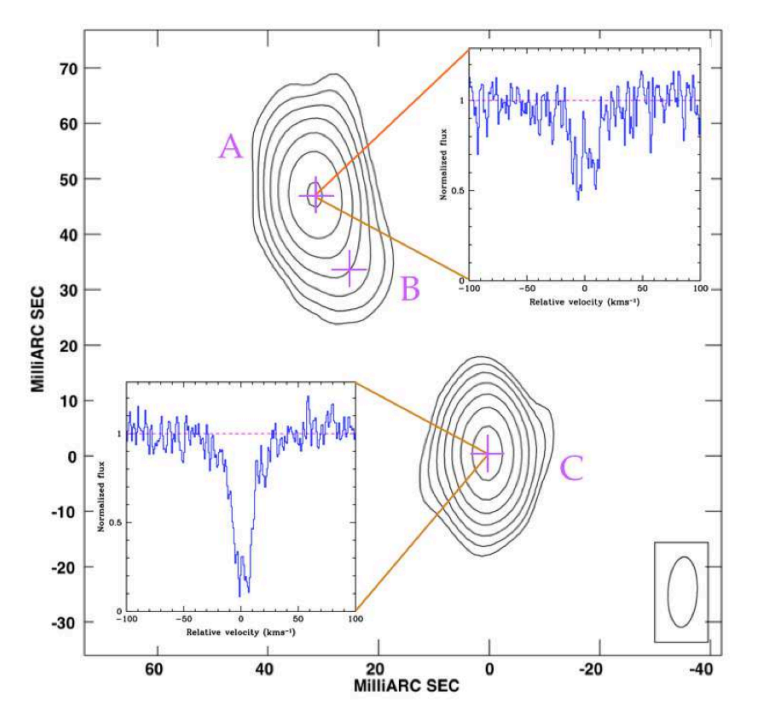
Brogan et al. 2004



Elmegreen et al. 2000

ISM OF EXTERNAL GALAXIES WITH VLBI

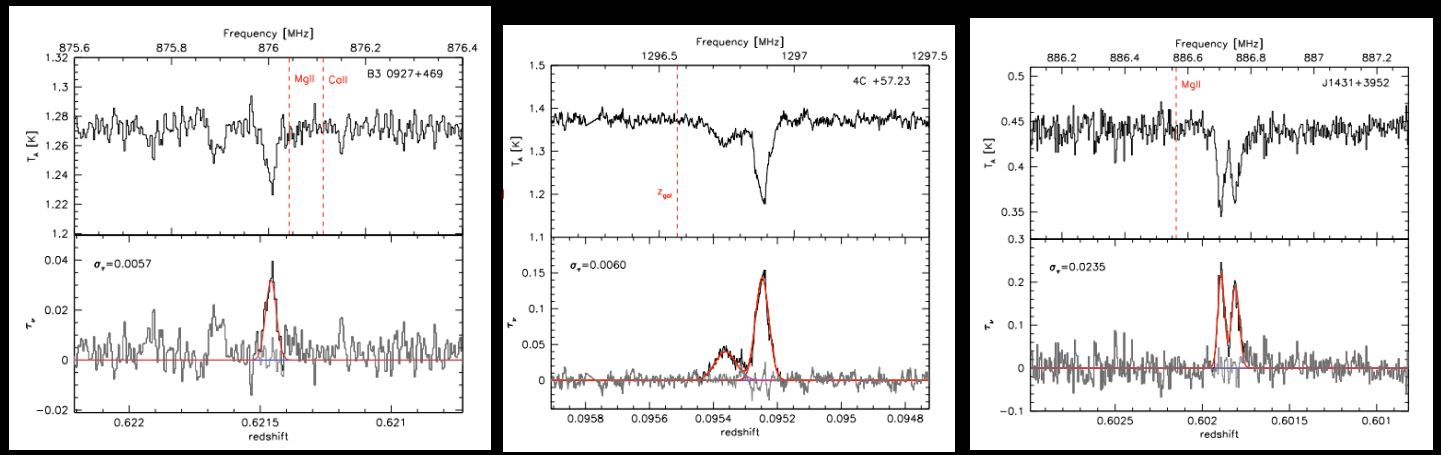




- VLBA HI spectrum shows significant differences between components separated by ≈ 90 pc
- Srianand et al. (2013) conclude that the cold absorbing gas is patchy on scales of 30-100 pc

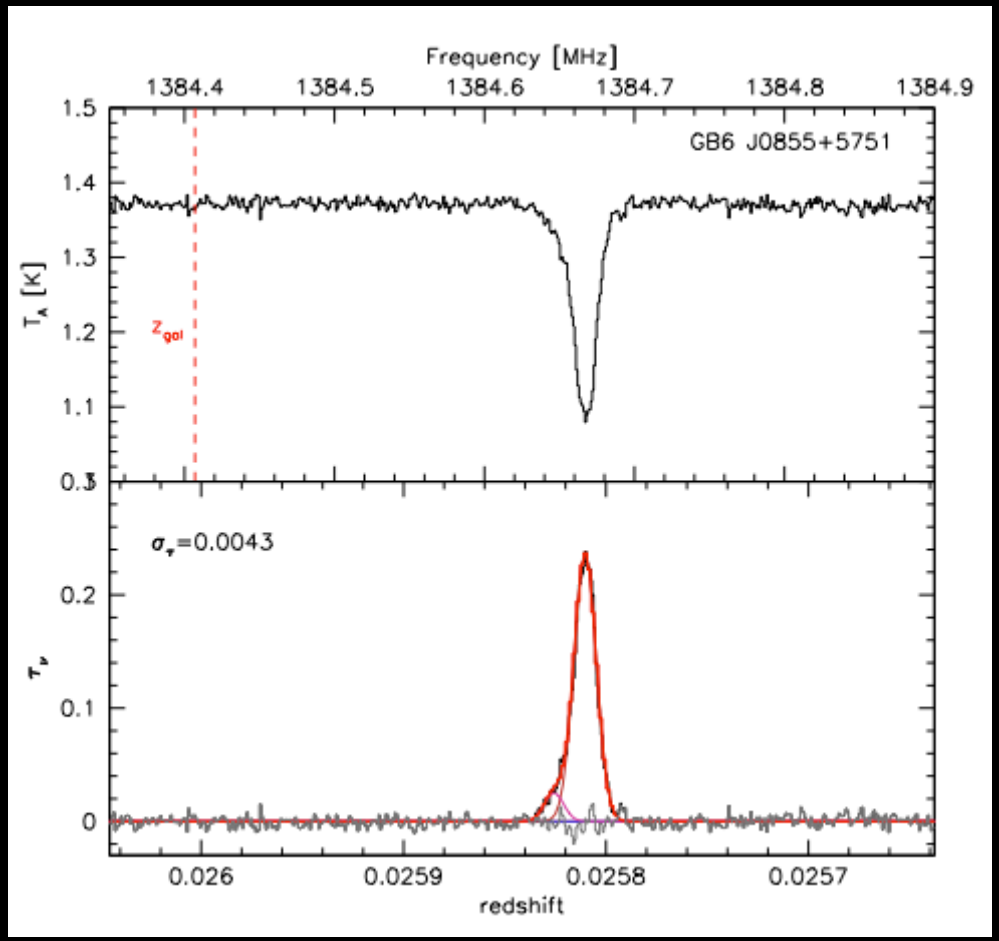
THE PARENT GBT HI SURVEY

- Small impact parameter radio-loud quasar-galaxy pairs
  - Select candidates from MgII, CaII, Ly-α absorbers, SDSS
  - Cross correlate with FIRST sources ($S_{1.4GHz}$ > 200 mJy and r < a few")
- 4 out of 24 candidates detected in HI



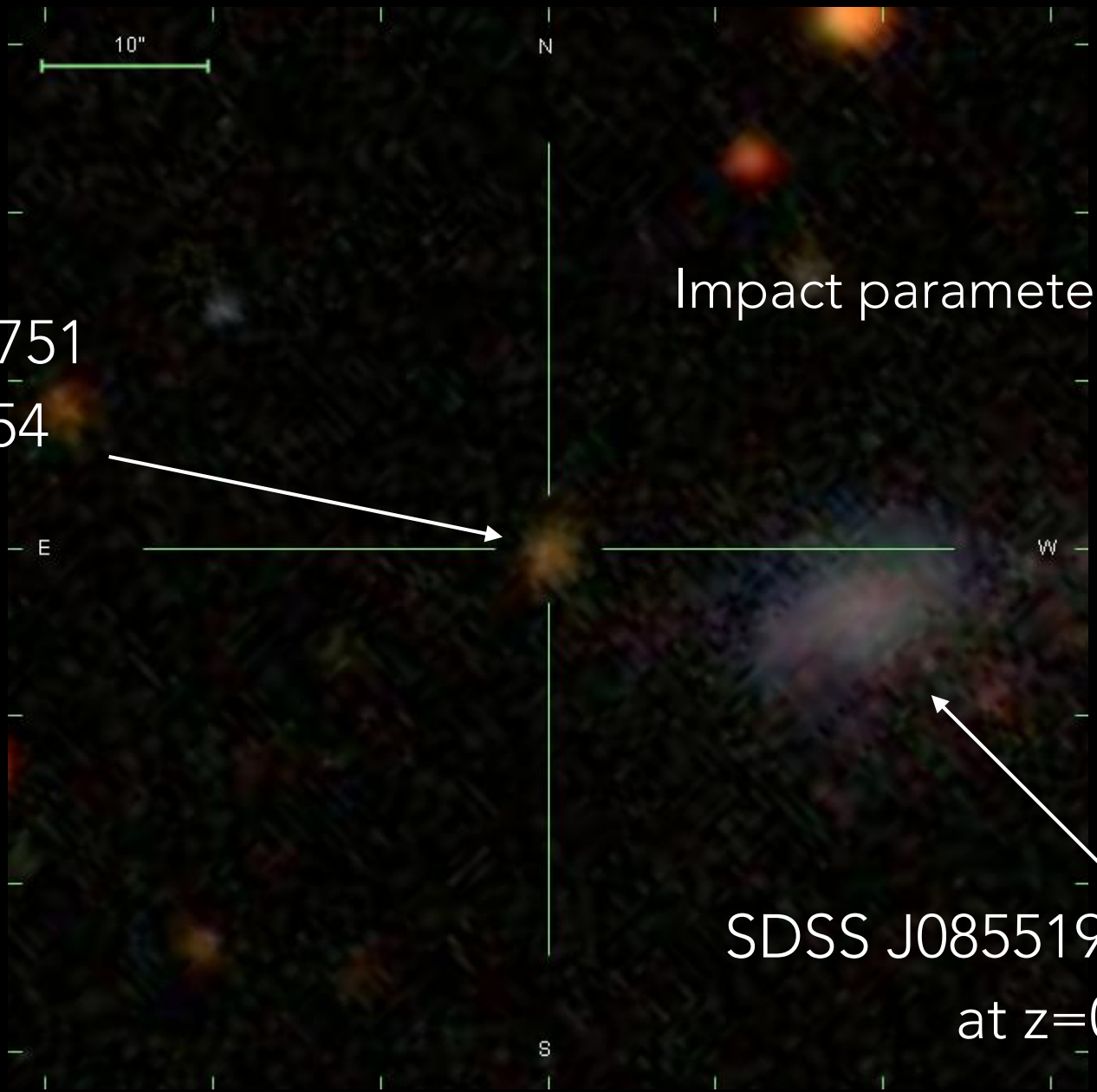
Zwaan et al. 2016

J0855+5751 GBT HI SPECTRUM



- Two components with σ = 1.5 km/s separated by ≈ 4 km/s

SDSS IMAGE

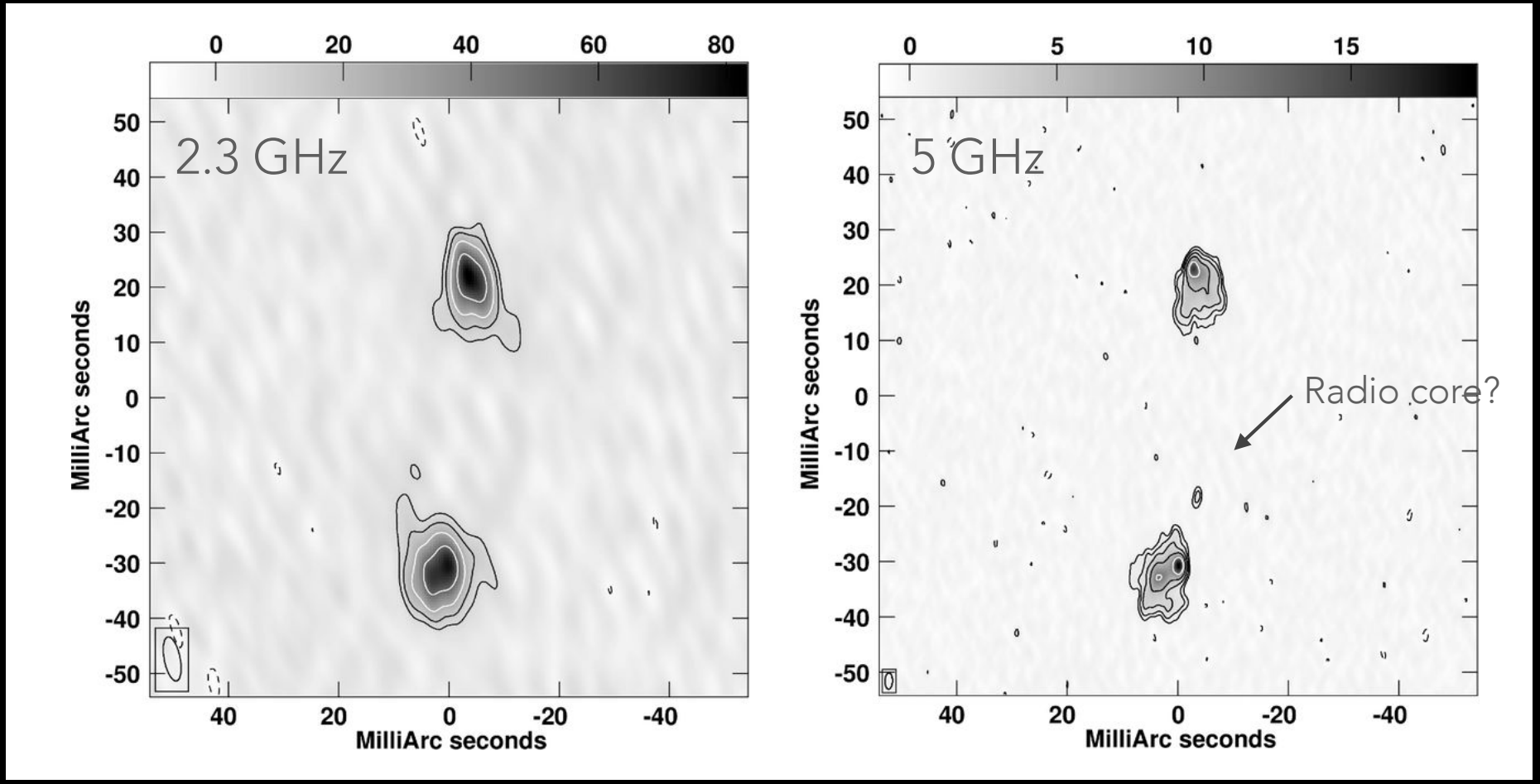


J0855+5751
at z=0.54

Impact parameter ≈ 7 kpc

SDSS J085519.05+575140.7
at z=0.026

PREVIOUS VLBI OBSERVATIONS



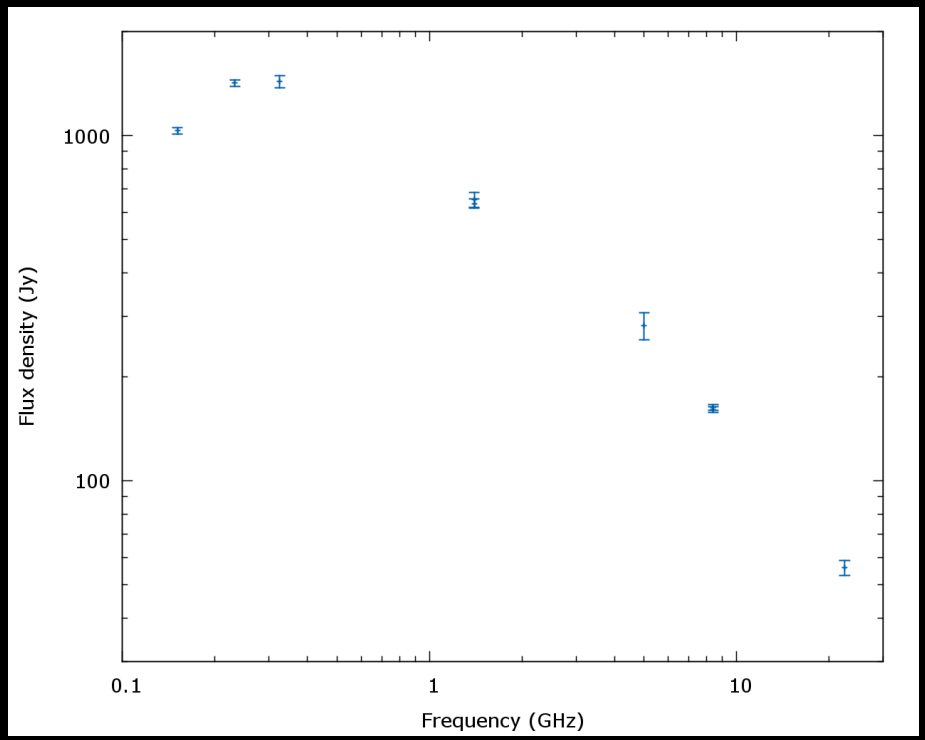
VLBA Calibrator Survey
(Beasley et al. 2002)

VLBA Imaging and Polarimetry Survey
(Helmboldt et al. 2007)

Re-reduced from archival data

J0855+5751 PROPERTIES

- We measure redshift with WHT
  - $z = 0.541\,86$
- Projected size < 0.5 kpc
- Radio SED peak ≈ 300 MHz
- Unpolarized
- J0855+5751 fulfils many criteria of CSS/GPS sources

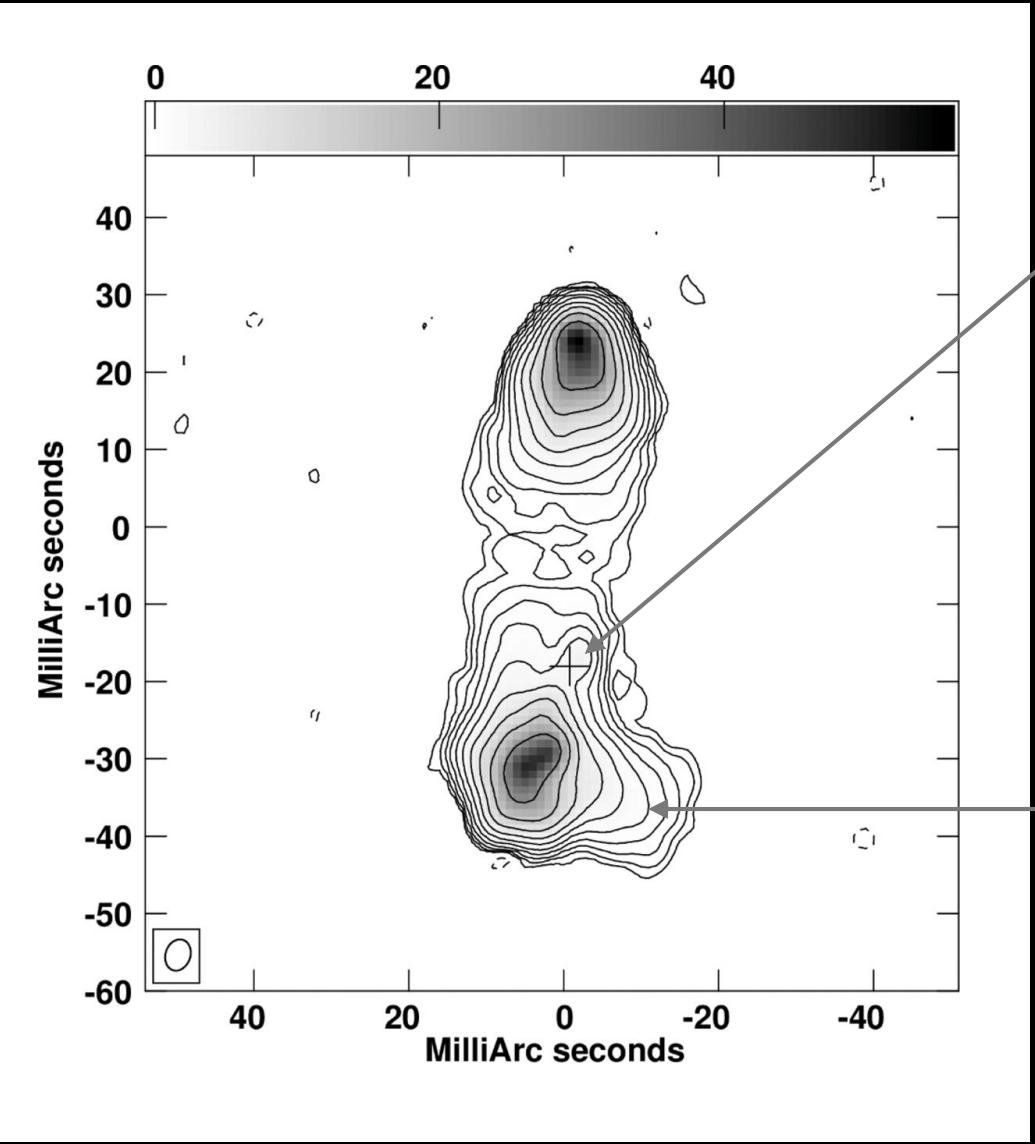


NEW GLOBAL VLBI OBSERVATIONS

- EVN + VLBA
  - Angular resolution@ 1385 MHz: 4 mas = **2 pc at z = 0.026**
- In-beam phase calibrator!
  - J0854+5757 = 0850+581
  - 8′ from target (not usable for Wb)
- Used 4 x 2 MHz subbands
  - Continuum sensitivity = 18 μJy/beam
- One subband for HI line
  - **Spectral resolution = 200 m/s**, sensitivity of 1.4 mJy/channel

Goal was to investigate ISM on scales between 2-30 pc

CONTINUUM IMAGE



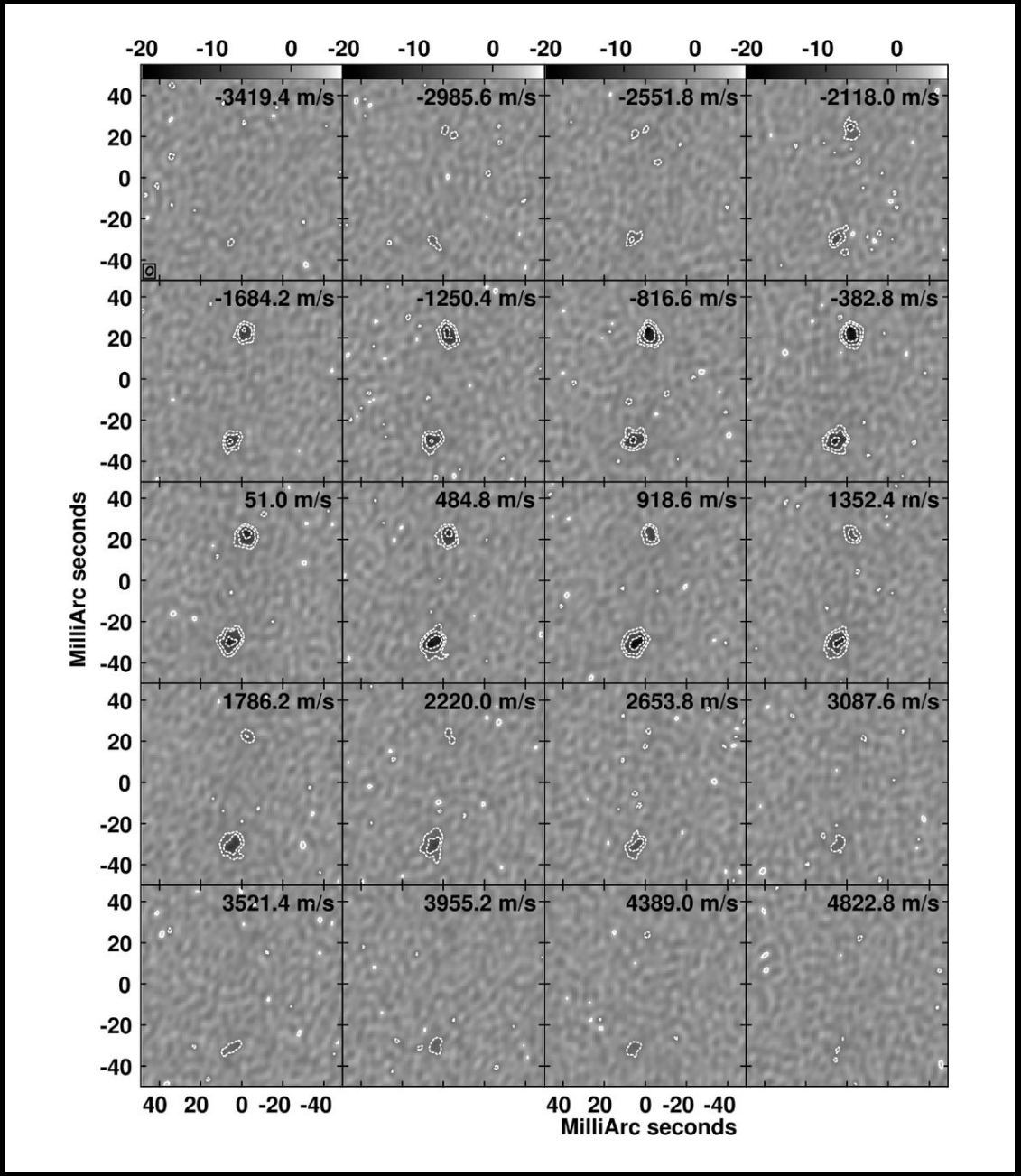
Core component seen in 5 GHz map

C-band peak flux = 2.1 mJy/beam
L-band peak flux = 3.4 mJy/beam
$\alpha \approx -0.4$

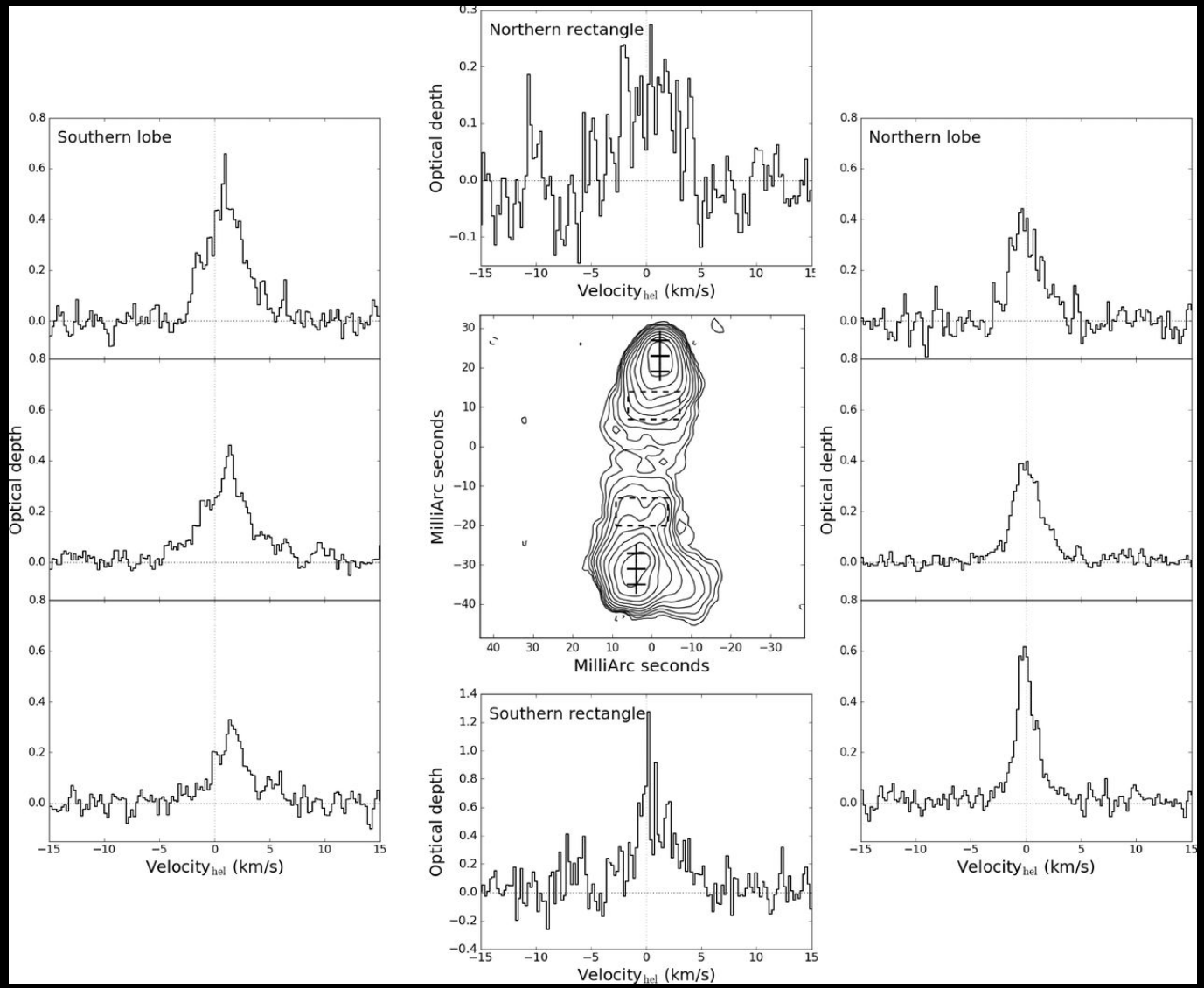
Distorted lobe with deflected jet

Interaction with ISM of host galaxy

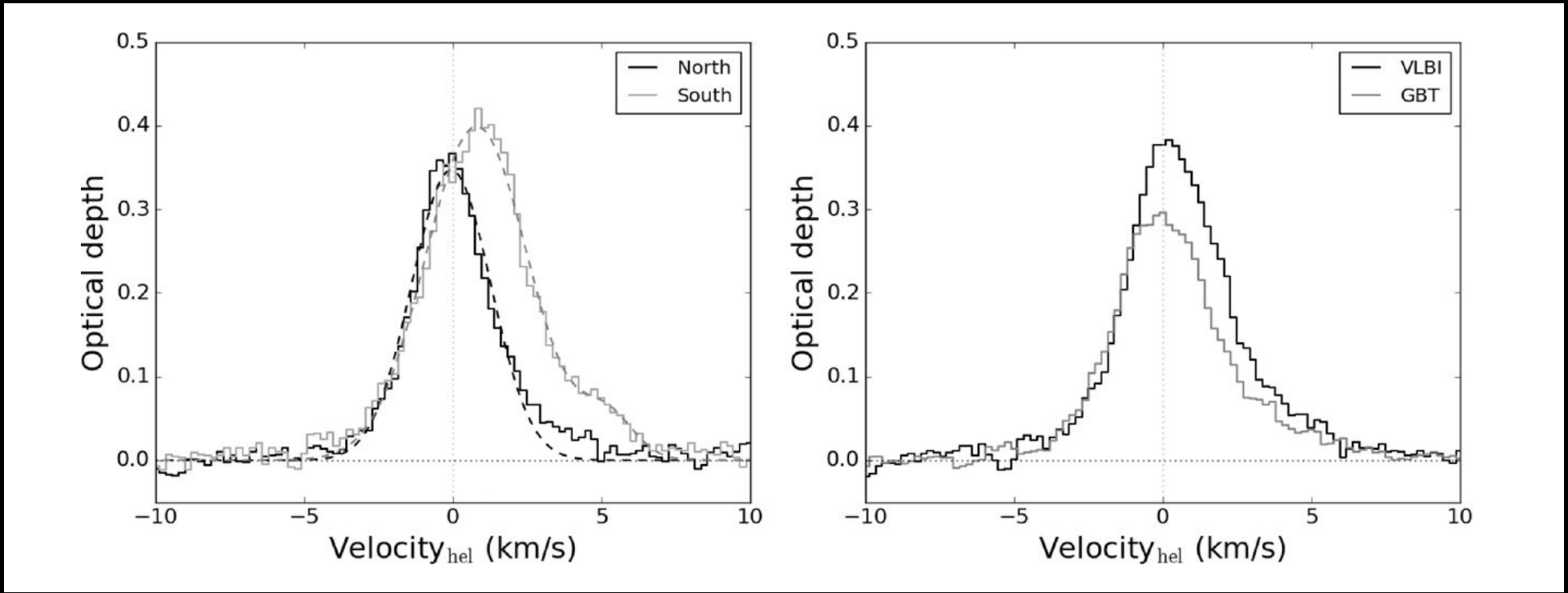
H I ABSORPTION IN THE FOREGROUND GALAXY



OPTICAL-DEPTH SPECTRA OF DIFFERENT SIGHT-LINES



COMPARING BOTH LOBES



Velocity dispersion as narrow as 0.9 km/s

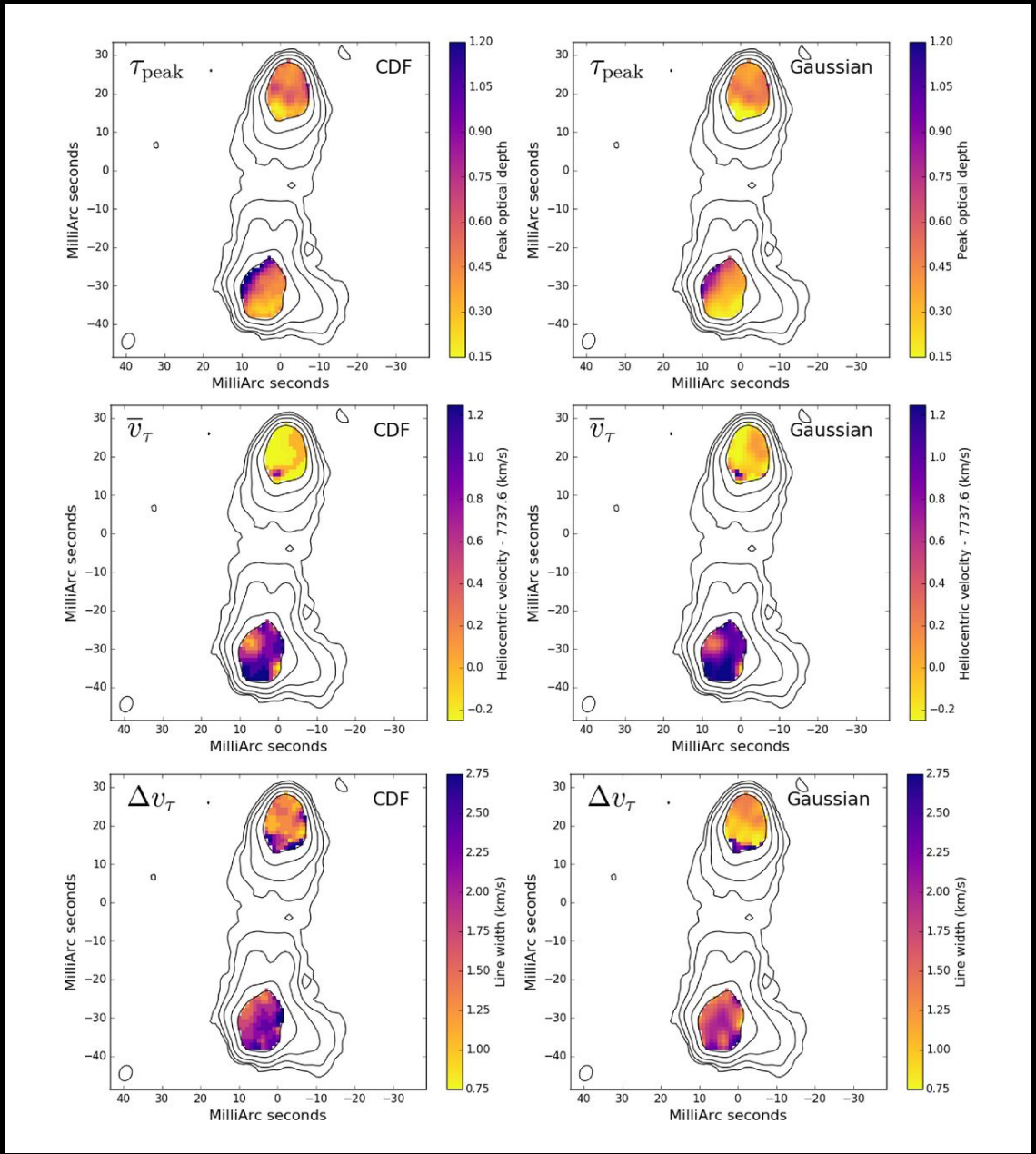
$$T_{\rm k} \leq \frac{m_{\rm H}\Delta v^2}{k\,8\ln 2} = \frac{1.2119\times10^2\,\Delta v^2}{8\ln 2},$$

Kinetic temperatures < 100K

Looking at the CNM

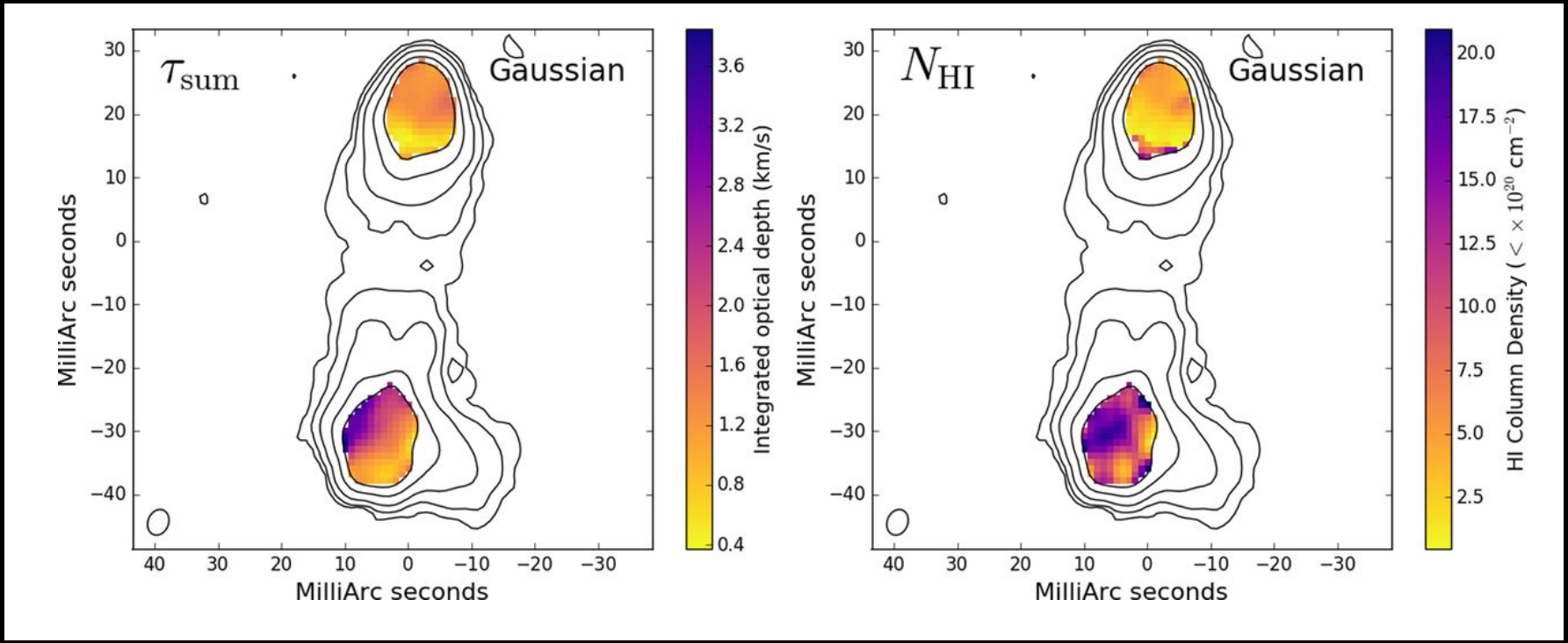
MAPS OF PEAK OPTICAL DEPTH, VELOCITY OF MAXIMUM OPTICAL DEPTH AND VELOCITY WIDTH

Left: cumulative distribution function (CDF) of the optical depth as a function of frequency



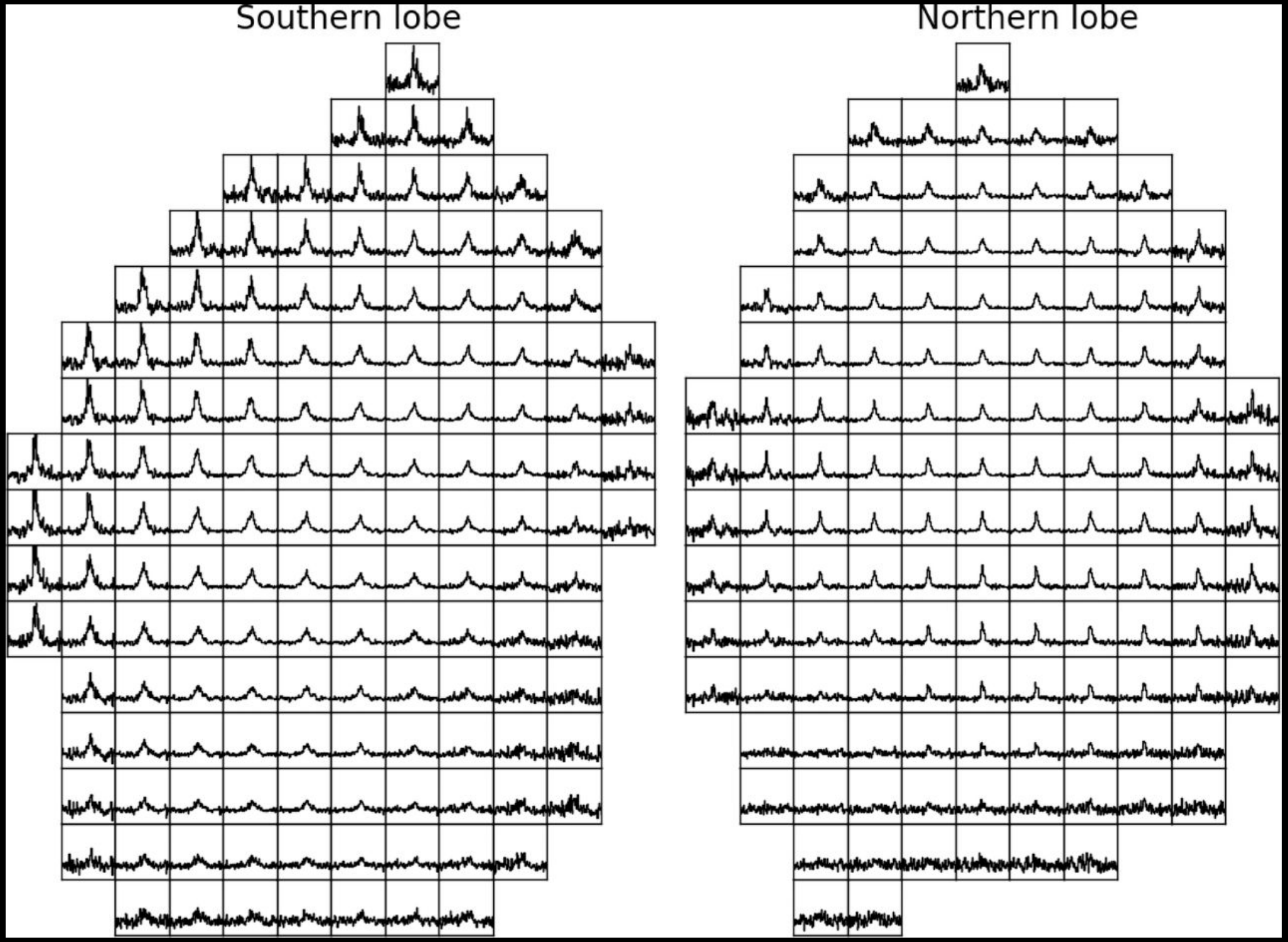
Right Gaussian fits

MAPS OF OPTICAL DEPTH AND COLUMN DENSITY



Column density maps calculated by assuming that spin temperature is equal to kinetic temperature

$$N_{\rm HI} = 1.823 \times 10^{18} \, (T_{\rm s}/f) \int \tau {\rm d}v$$


Southern lobe
Northern lobe

INTERPRETATION

- Large and apparently coherent variations in line width are visible
- Total τ - **and column density** - **vary by factor of 5 over 12 mas or 6.3 pc**
- We observe structure on scales **between 2 and 30 pc**
- No sight-lines that do not intercept absorbing H I gas
- We see a single coherent cold structure of at least 35 pc, larger than the largest CNM clouds featured in the McKee & Ostriker (1977) model
- Further evidence that the **blobby sheet model of Heiles & Troland (2003)** is also appropriate for external galaxies
- We interpret peaks seen within the broader line profile as individual cold cores (blobs) located within the larger-scale sheet

IMPLICATIONS

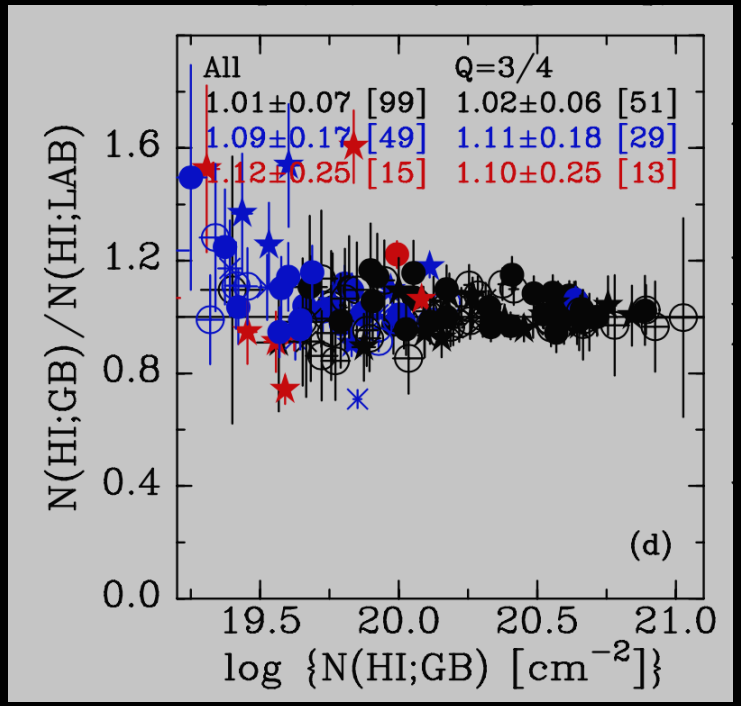
- T_s depends on Lyα (column density) and 21-cm (optical depth)
- Assumption: same gas is probed by the optical and radio
- Kanekar et al. (2014) use smoothed H I emission maps of LMC → estimates of T_s are correct within 10%
- Our data show that H I can be unevenly distributed on smaller scales
- T_s values may significantly less reliable than suggested.

COMPARISON TO THE MILKY WAY

- Wakker et al. (2011) found N(Lyα)/N(HI) in the Milky Way has an average of 1 and a dispersion of about 10%

- Lazio et al. (2009) use VLBI absorption in the Milky Way and find τ variations up to 70%.

- Clearly we need to identify more systems like J0855 to understand the small scale structure in the ISM



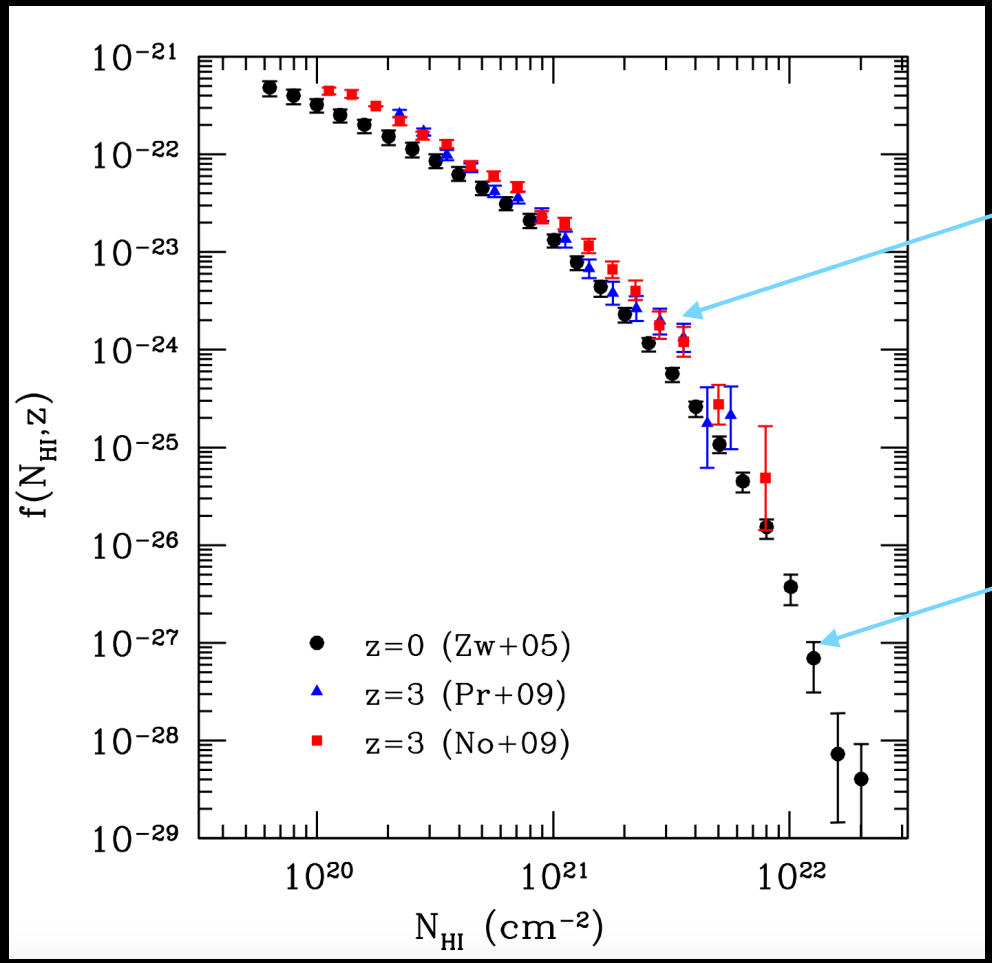
→ ASKAP-FLASH

The First Large Absorption Survey in HI

CONCLUSIONS

- In a DLA that arises in the far outskirts of a low mass galaxy, we detect strong variations (factor 5) in N_{HI} on scales of 2 to 30 pc.
- Not clear whether this is representative for all DLAs.
- T_s measurements may be highly uncertain
- Need to identity more systems like J0855

HI COLUMN DENSITY DISTRIBUTION FUNCTION



Lyα absorption, sub-pc scales

21-cm emission, kpc scales