On the interplay between gas and radio AGN: The HI absorption "Zoo"

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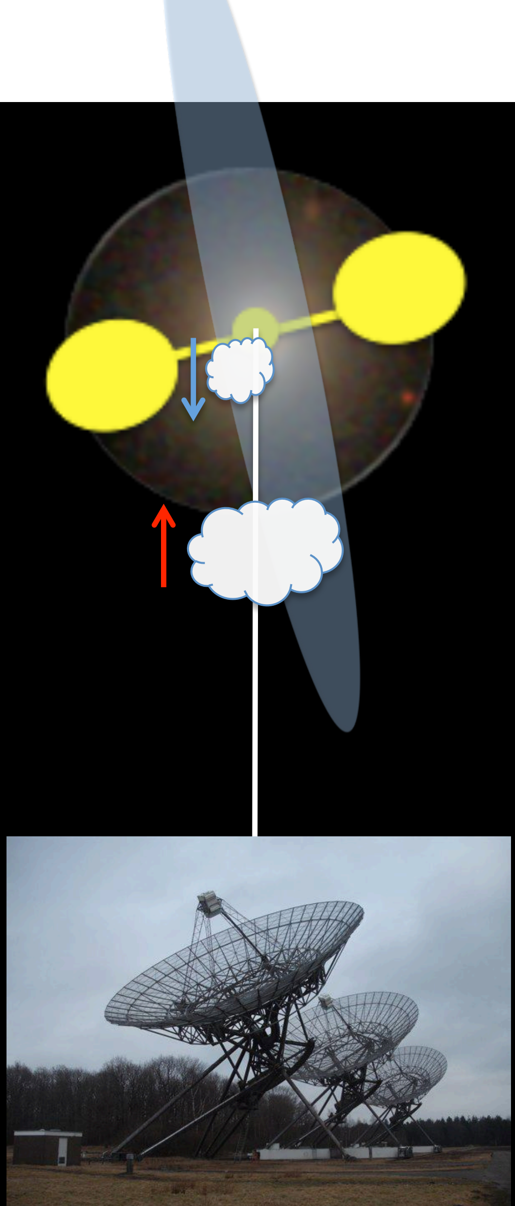
Neutral hydrogen (HI) gas in radio AGN

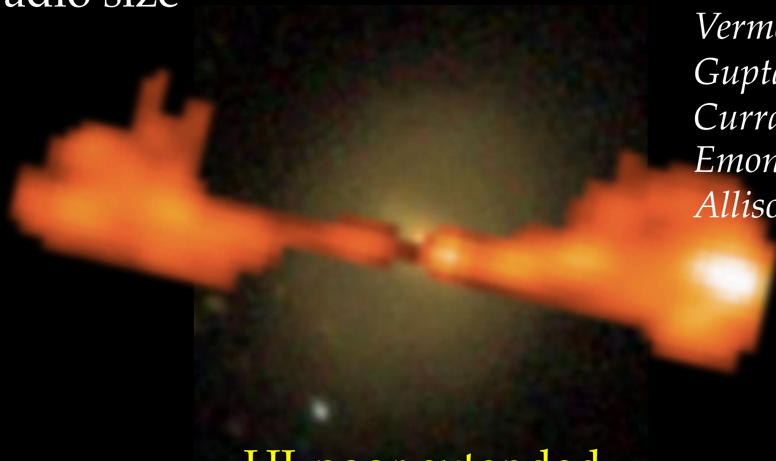


- Gas accretion onto the central black hole (BH) of galaxies is thought to provide the necessary fuel supply for (radio) AGN activity.
- HI can be detected in absorption if the gas is located in front of the continuum of the AGN
- Complex kinematics : disks, inflow / outflow (fuelling / feedback) *Gas plays many different roles in AGN!*

Compact vs. extended AGN

Van Gorkom+1989
Morganti+2001
Pihlstrom+ 2003
Vermeulen+2003
Gupta+2006
Curran+ 2010
Emonts+2010
Allison+2014

- Trend between HI detection rate & radio size



HI-rich compact CSS and GPS

- < 10 kpc
- < 10^5 yr young AGN
- 30 - 60% detection rate

HI-poor extended

- up to Mpc scales
- < 10^8 years
- 10 - 25% detection rate

HI involved in the AGN fuelling processes

Gas depleted as AGN grows older

Our flux-selected AGN sample

- Snapshot WSRT observations (4 hours) to collect a large, homogeneous sample of AGN→ HI absorption stacking

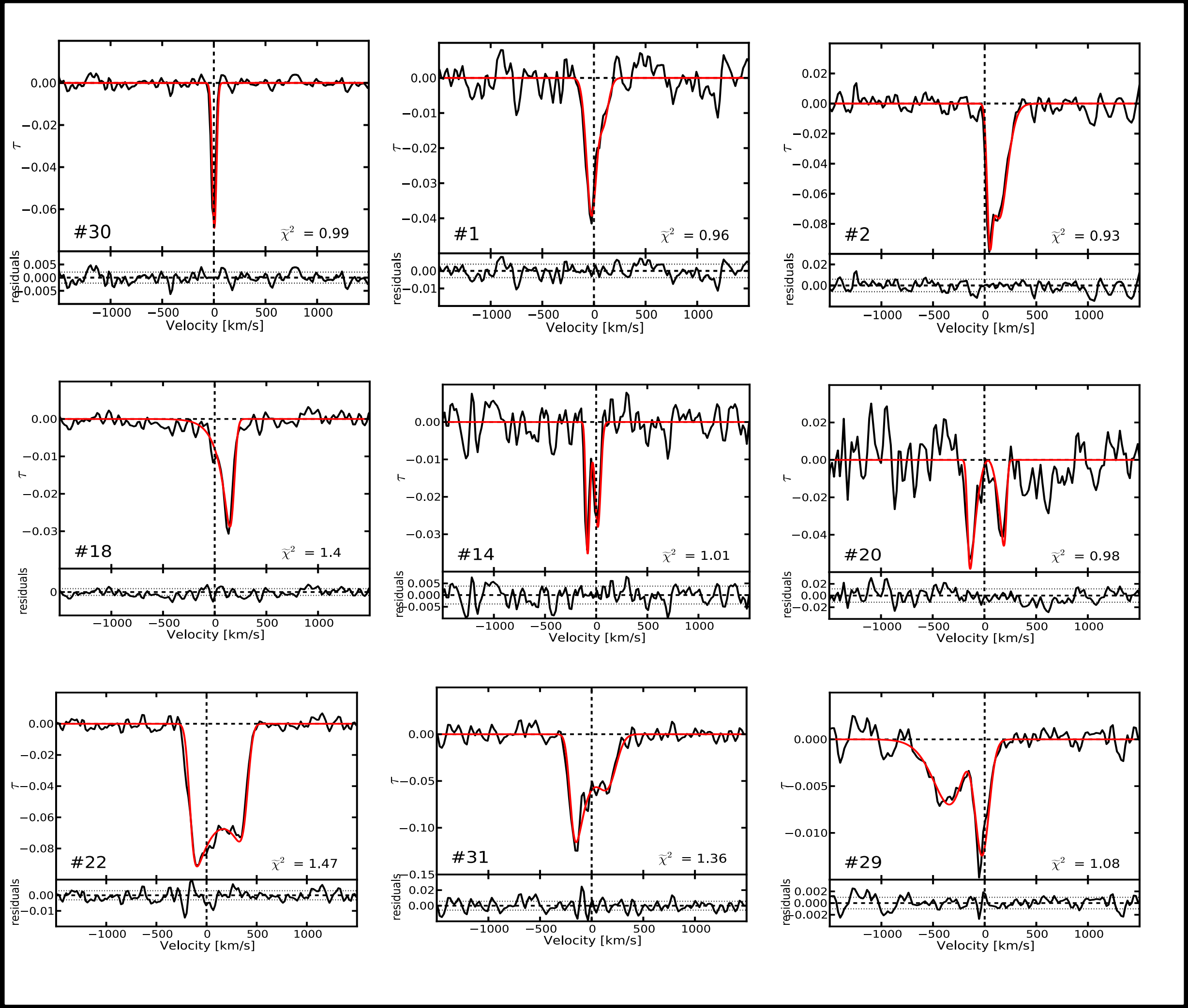
Westerbork Synthesis Radio Telescope (WSRT)

The AGN sample:

- 101 sources in the SDSS spectroscopic catalog
- $0.02 < z < 0.23$
- $S_{1.4GHz} > 50$ mJy peak flux in the FIRST survey

- Preparation for future blind HI surveys: ASKAP, Apertif, MeerKat… SKA
- HI emission samples for comparison: Sauron, ATLAS^{3D}

32 detections! a few examples…



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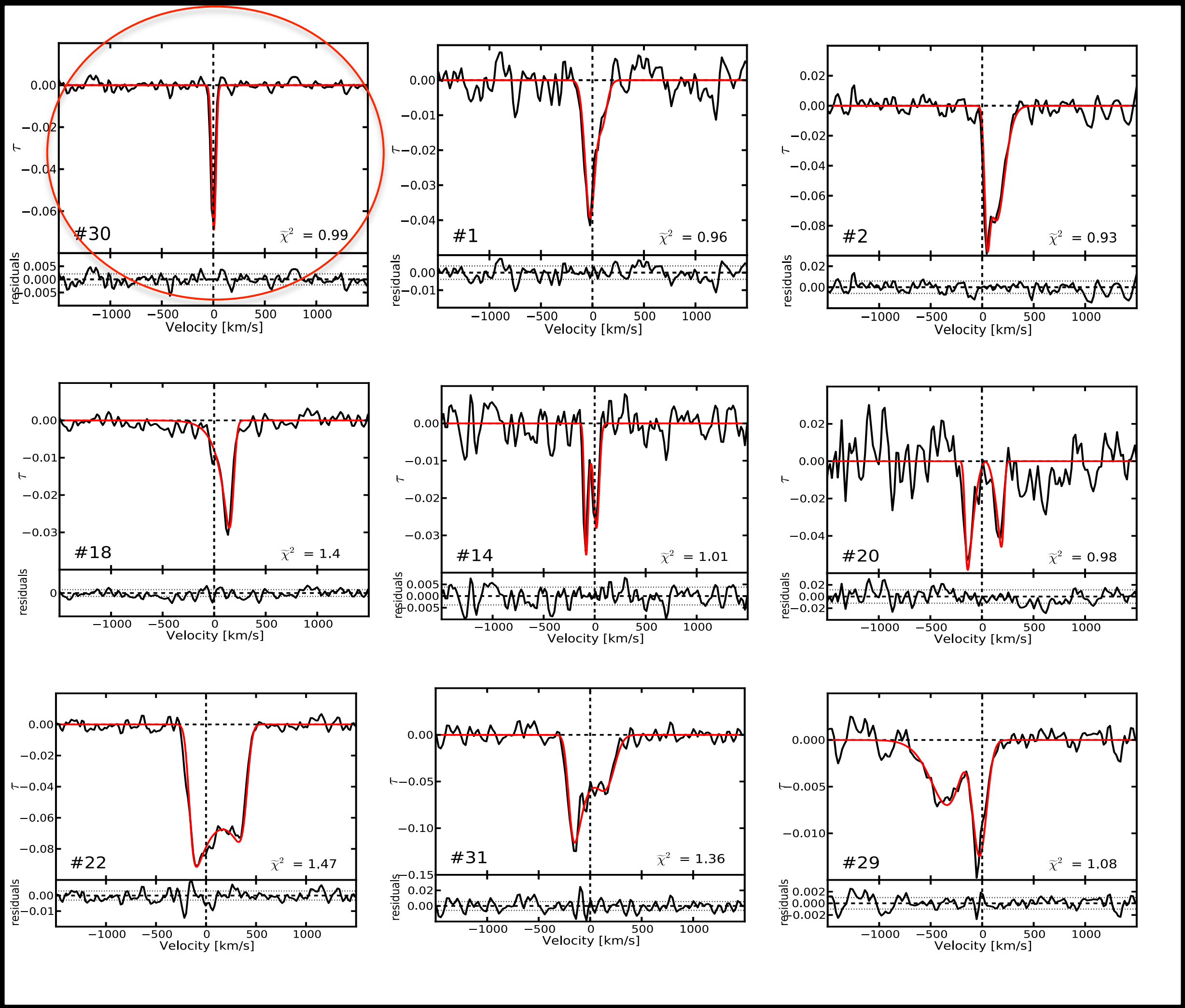

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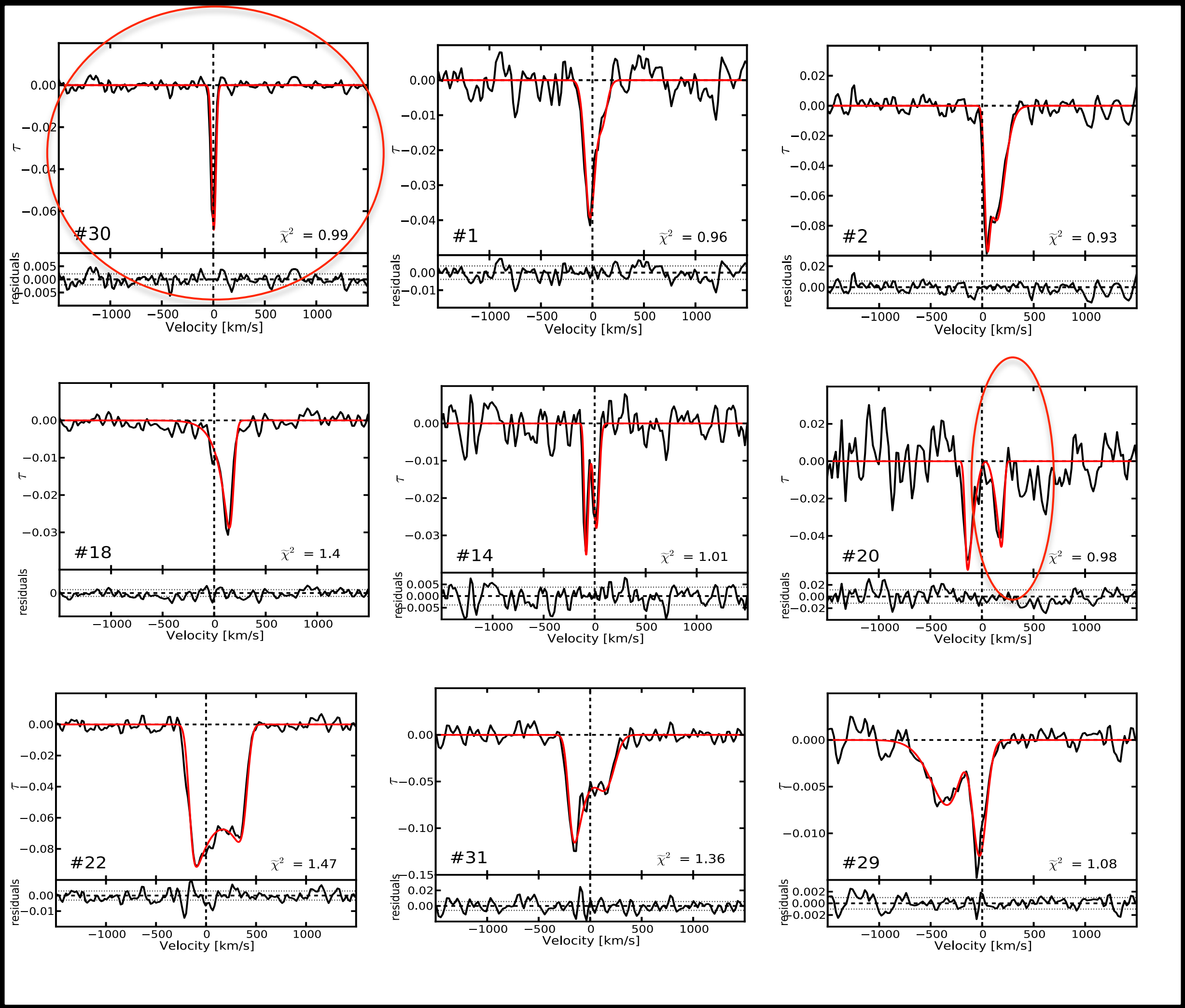

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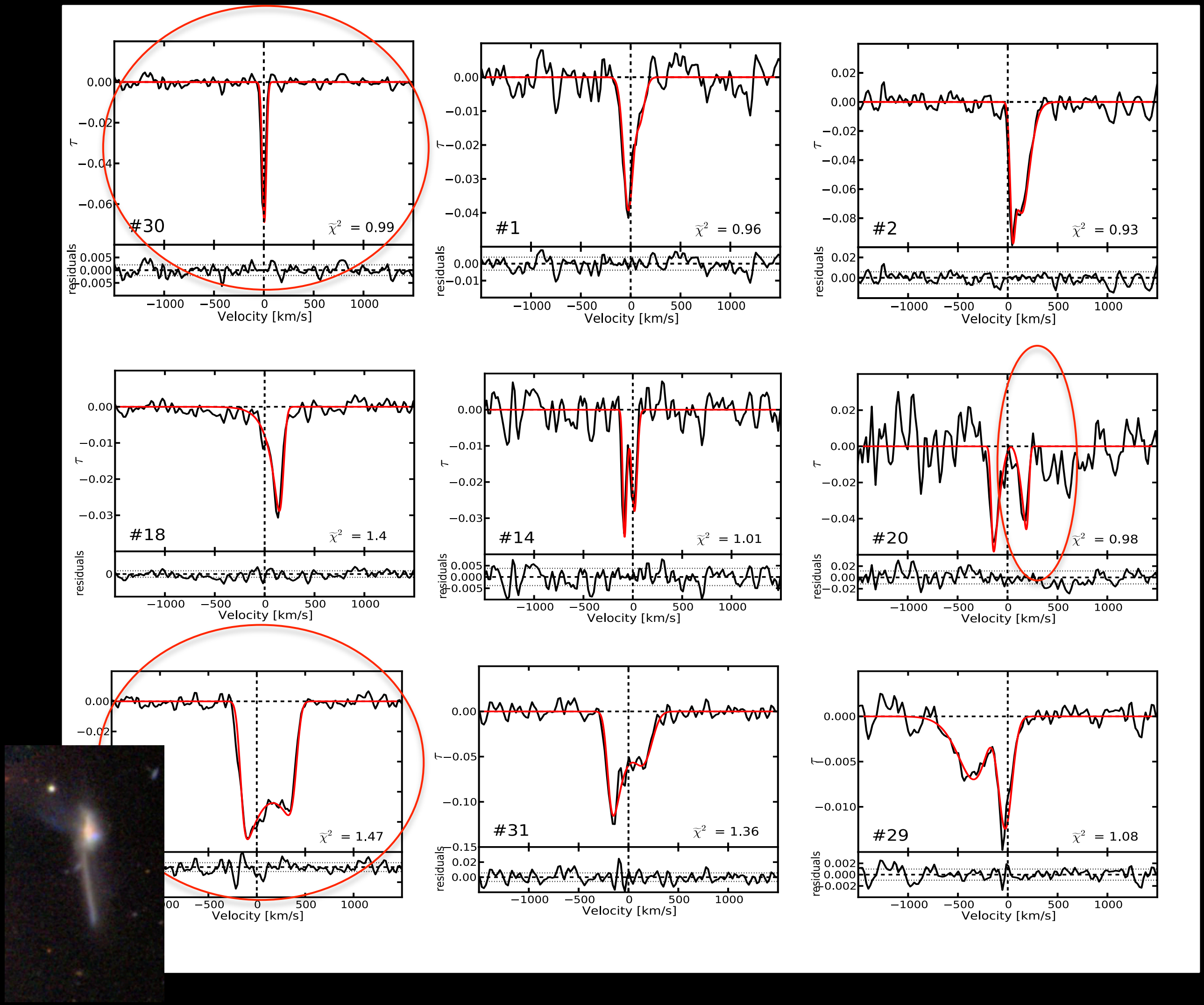
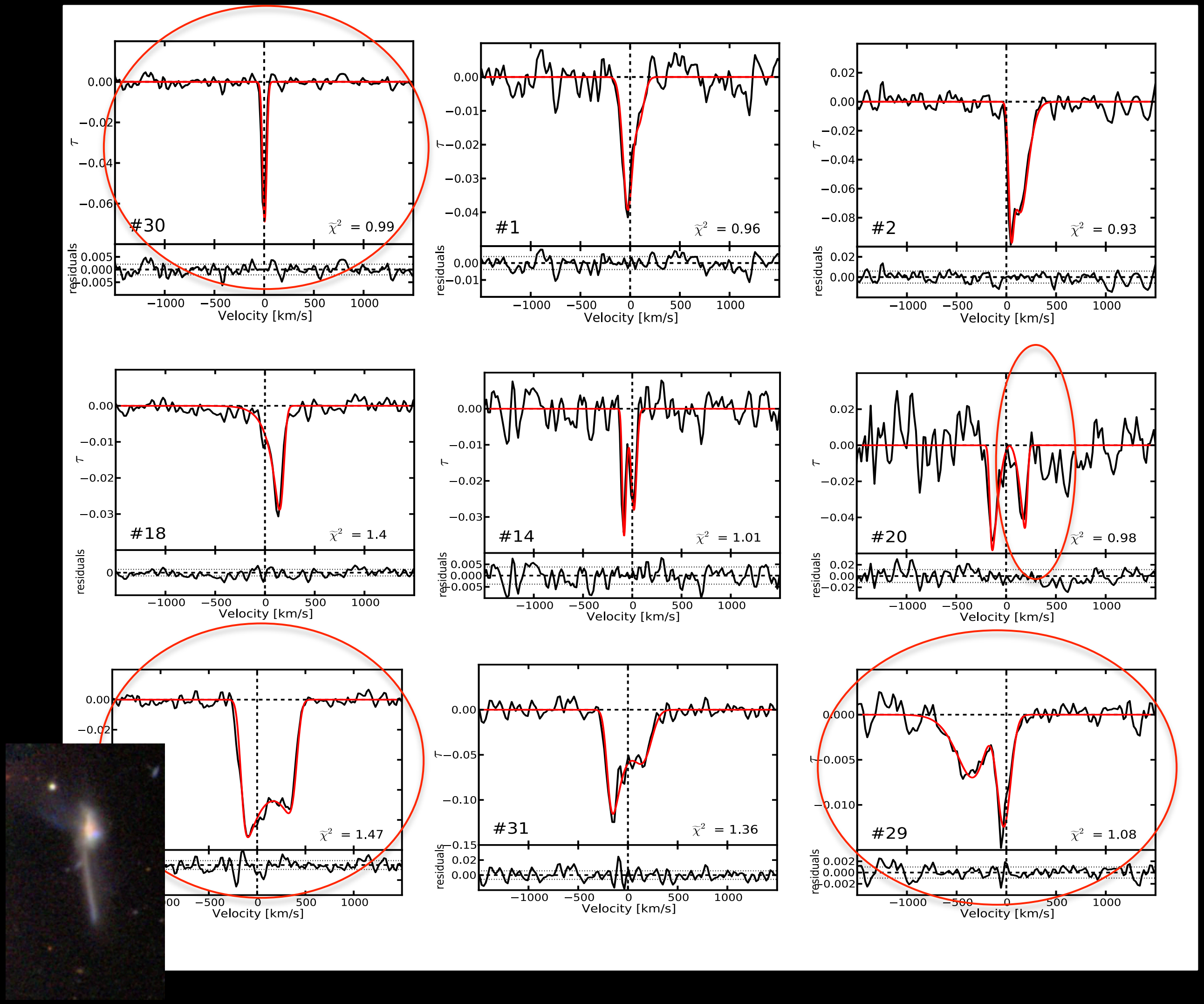


The HI absorption "Zoo"

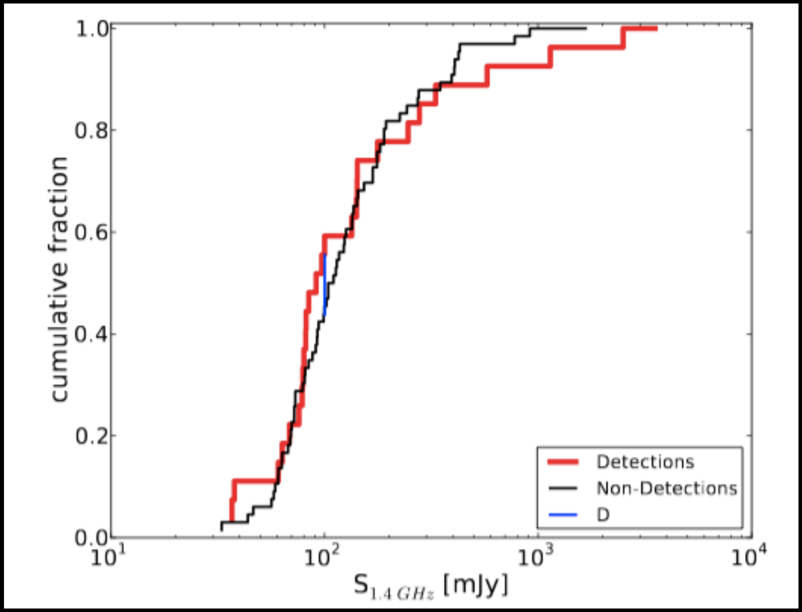
32 detections! a few examples…



The HI absorption "Zoo"

- 30 percent detection rate is representative above $\tau = 0.02 - 0.08$ (van Gorkom+ 1989, Emonts+ 2010, Allison+ 2014)

$\tau \sim S_{abs}/S_{cont}$

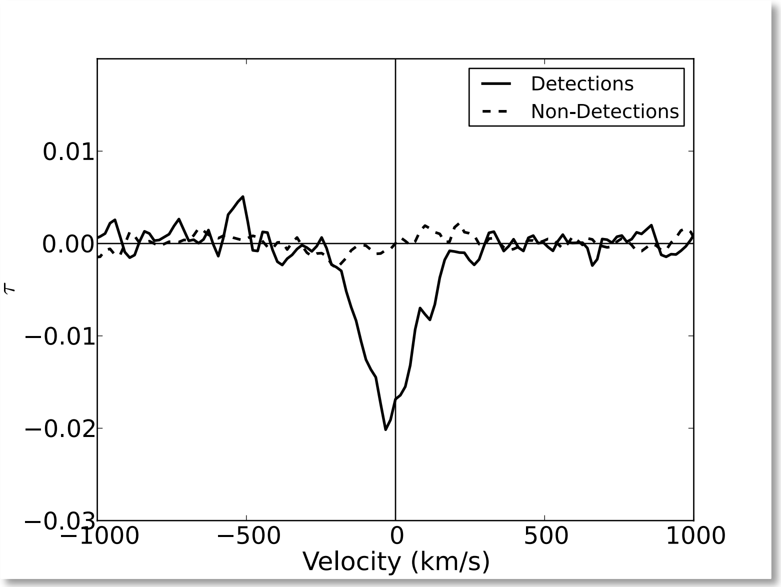


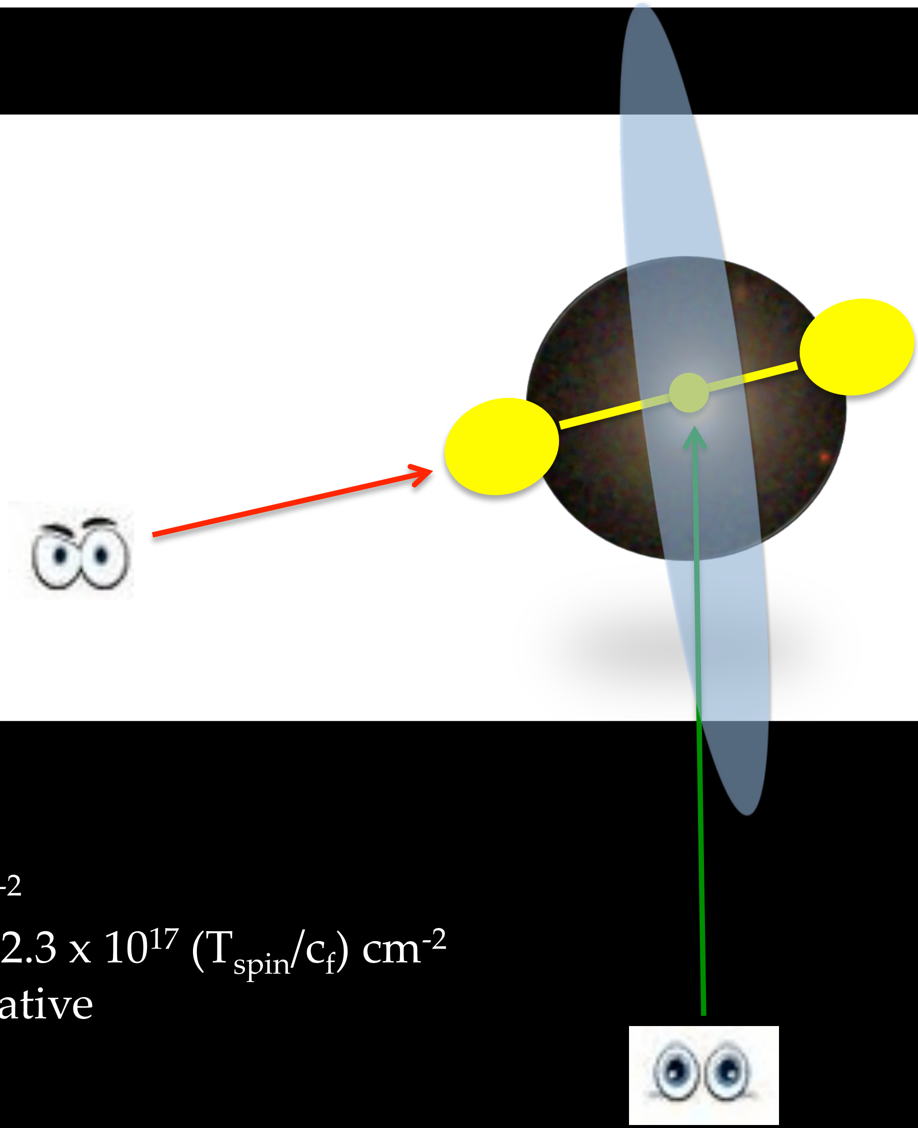
No continuum flux density dependence

- The detection of HI absorption is not biased towards brighter sources
- Good news for future surveys

HI absorption stacking

- Stacking is done in τ optical depth





Dichotomy in the stacked profiles

- Detections N(HI) ~ 7.4 x 10^{18} (T_{spin}/c_f) cm^{-2}
- Non-detections stay undetected N(HI) < 2.3 x 10^{17} (T_{spin}/c_f) cm^{-2}
  → 30 percent detection rate is representative

The nature of the HI absorption

… in compact (young) and extended (old) sources

ATLAS^{3D} HI emission study of early-type galaxies: 40% det. rate, 25% in disks/rings

Serra+ 2012

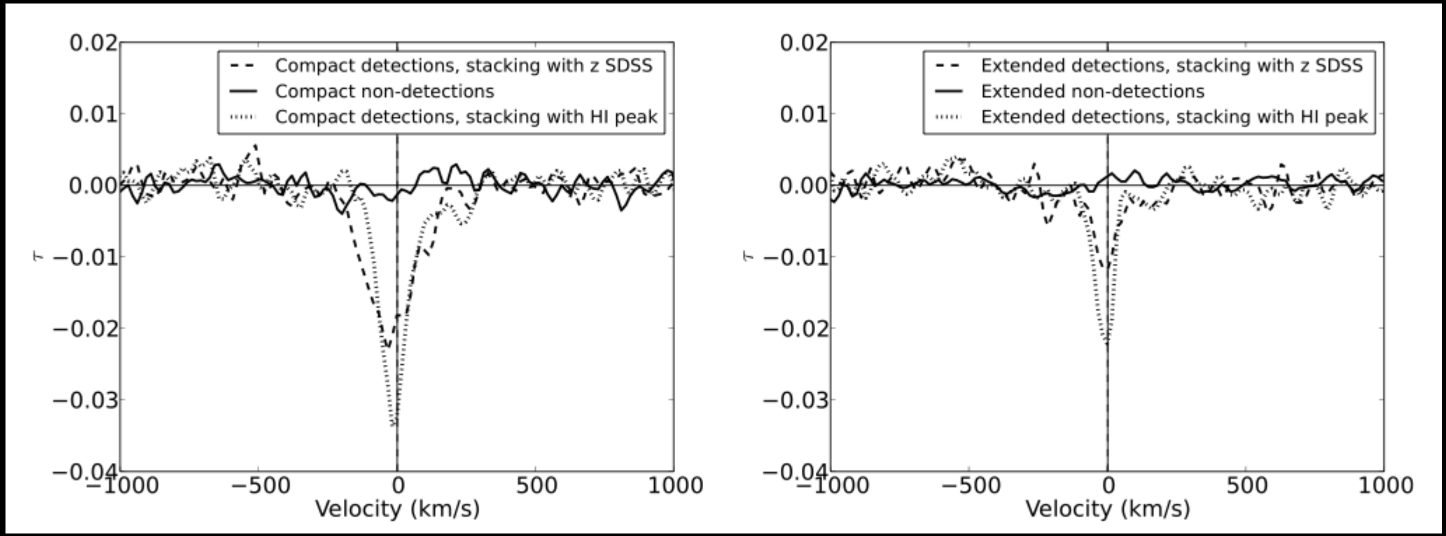
Compact vs. Extended

Det. rate$_{Com}$ ~ 42% (CSS, GPS: 55%)

Det. rate$_{Ext}$ ~ 16%

The nature of the HI absorption

… in compact (young) and extended (old) sources



Compact vs. Extended

Compact	Extended
Det. rate$_{Com}$ ~ 42% (CSS, GPS: 55%)	Det. rate$_{Ext}$ ~ 16%
FWHM$_{Comp}$ ~ 203 km/s	FWHM$_{Ext}$ ~ 120 km/s
N(HI)$_{Comp}$ ~ 8.5 x 10^{18} (T_{spin}/c_f) cm^{-2}	N(HI)$_{Ext}$ ~ 3 x 10^{18} (T_{spin}/c_f) cm^{-2}

- Unsettled gas involved in nuclear activity in (young) compact AGN

Complex HI profiles: broad range of line shapes and kinematics…

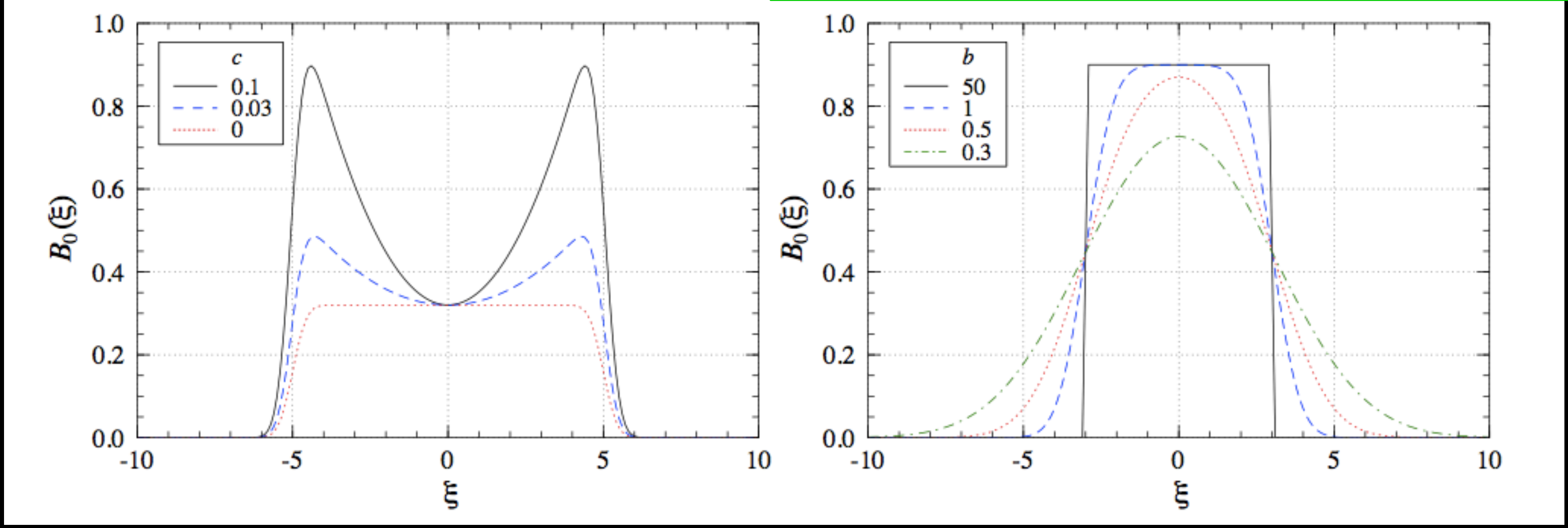
Parameterization of the profiles with the busy function

Constraining the morphology & kinematics of HI

The busy function

- Westmeier et al. 2014: suitable for fitting Gaussian & asymmetric lines

$$B_1(x) = \frac{a}{4} \times \left(\mathrm{erf}[b_1\{w + x - x_\mathrm{e}\}] + 1\right) \times \left(\mathrm{erf}[b_2\{w - x + x_\mathrm{e}\}] + 1\right) \times \left(c\,|x - x_\mathrm{p}|^n + 1\right). \quad (4)$$

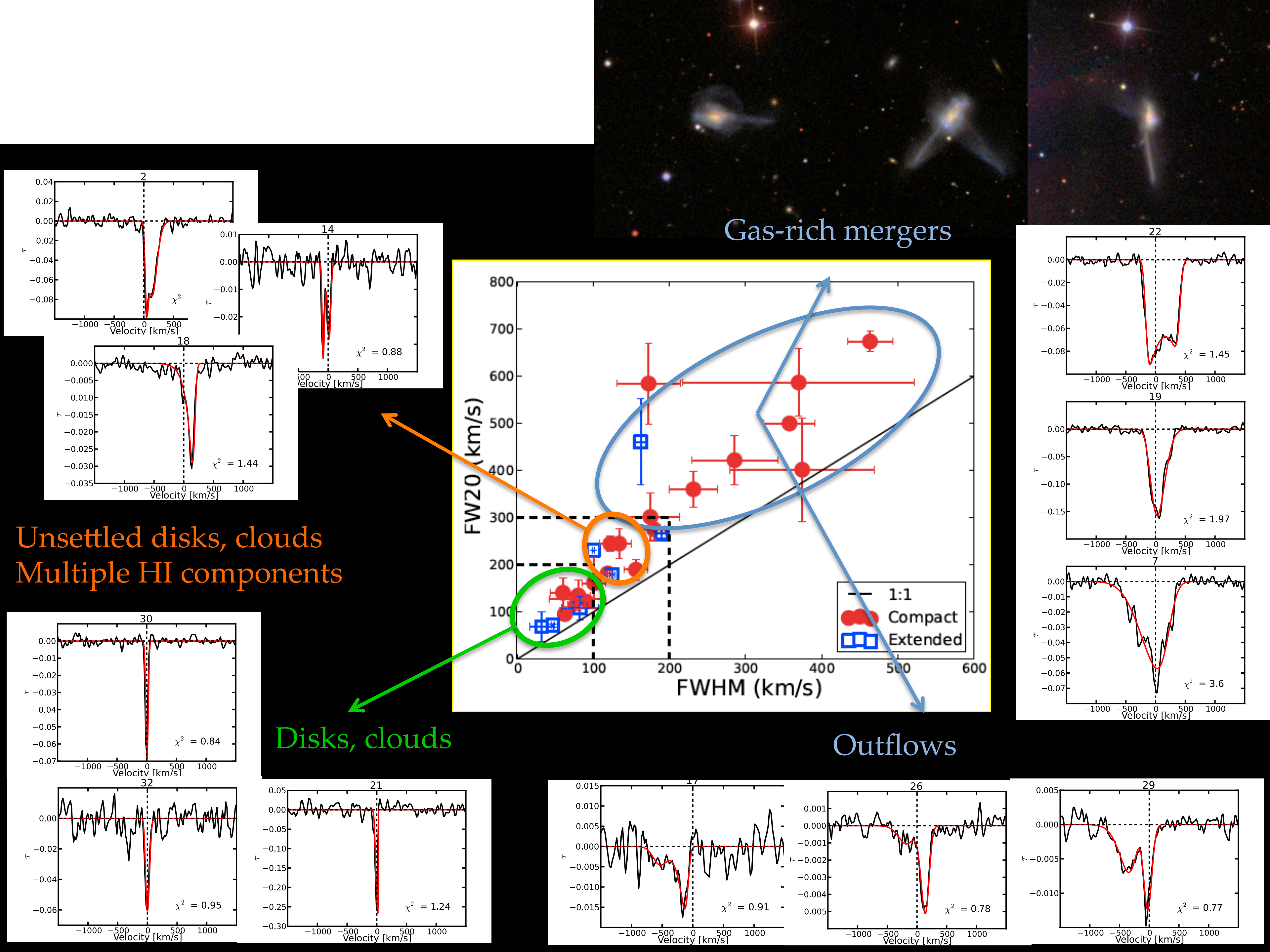


→ FWHM, FW20

→ Asymmetry

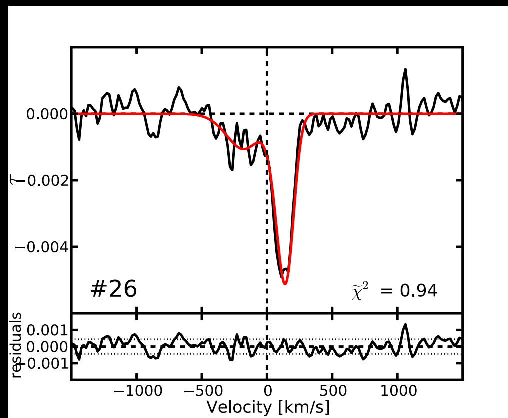
→ blueshift/redshift

- Kinematics and morphology of the gas in an automatic way
- Test the results of stacking

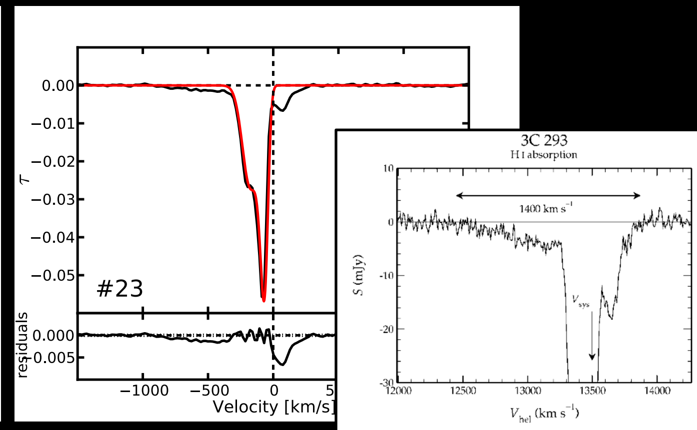


Gas-rich mergers
Unsettled disks, clouds
Multiple HI components
Disks, clouds
Outflows
FW20 (km/s)
FWHM (km/s)
1:1
Compact
Extended
Velocity [km/s]
χ^2 = 0.88
χ^2 = 1.44
χ^2 = 0.84
χ^2 = 0.95
χ^2 = 1.24
χ^2 = 0.91
χ^2 = 0.78
χ^2 = 0.77
χ^2 = 1.45
χ^2 = 1.97
χ^2 = 3.6

HI outflows (jet-cloud interactions)

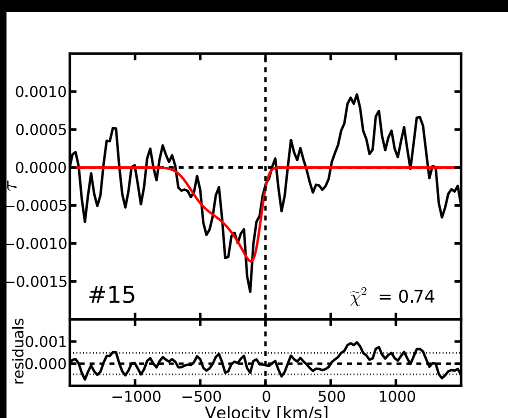


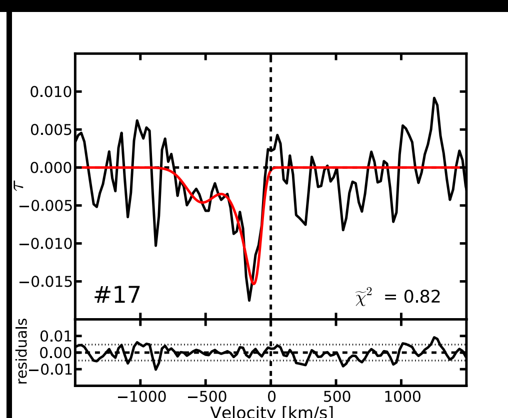
3C 305, Morganti+ 2005

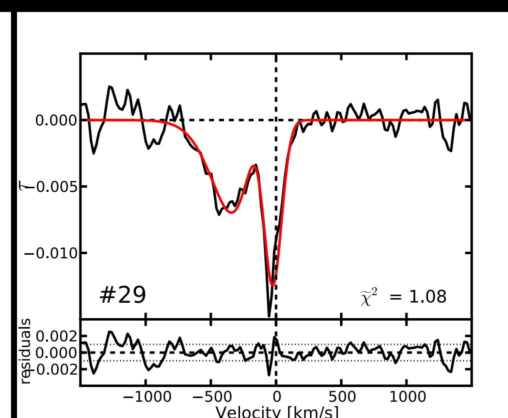


3C 293 Morganti+ 2003

Tentative outflows in compact sources







- 5% of the total sample has an outflow
- $t_{AGNcycle} \sim 10^8$ yr → with 5% detection rate $t_{outflow} \sim$ few Myr

Summary

Gereb+ 2014, 2015, A&A
HI absorption Safari, F. Maccagni+, extra 152 sources
Stay tuned!

- Above τ of a few percent detection rate of HI is 30%
  -> lots of new detections with future surveys, even outflows!

- If the HI dichotomy holds at lower tau (?) – perhaps stacking is more useful for studying/comparing groups of objects rather than pushing to lower detection limits

- Compact vs. Extended: detection rate & stacking – different tau, FWHM, N(HI)

- Busy function → deriving HI parameters

- Outflows driven by jet-cloud interactions are likely to occur in the compact AGN phase
  $t_{outflow}$ ~ few Myr

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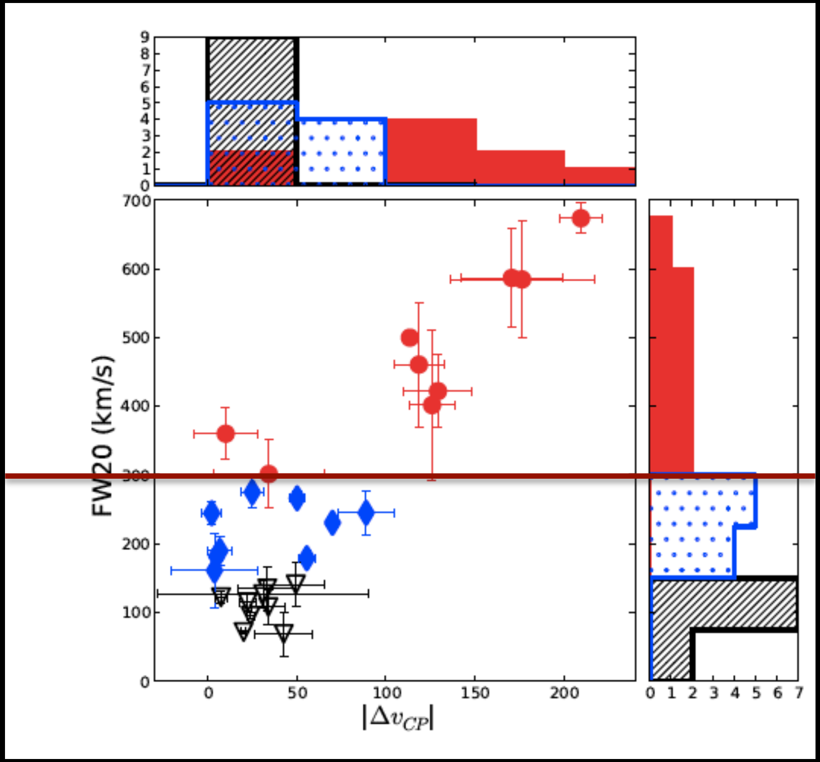
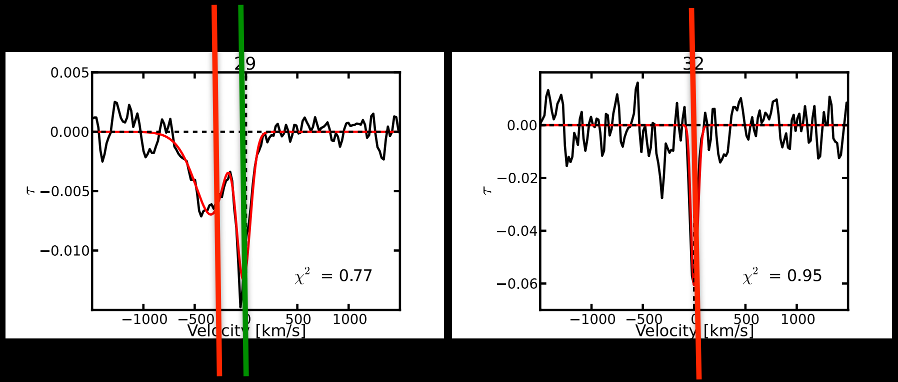
The nature of broad asymmetric lines



Asymmetry: $v_{Centroid\_20\%} - v_{Peak}$

$v_{Centroid}$ measured at 20% of peak intensity

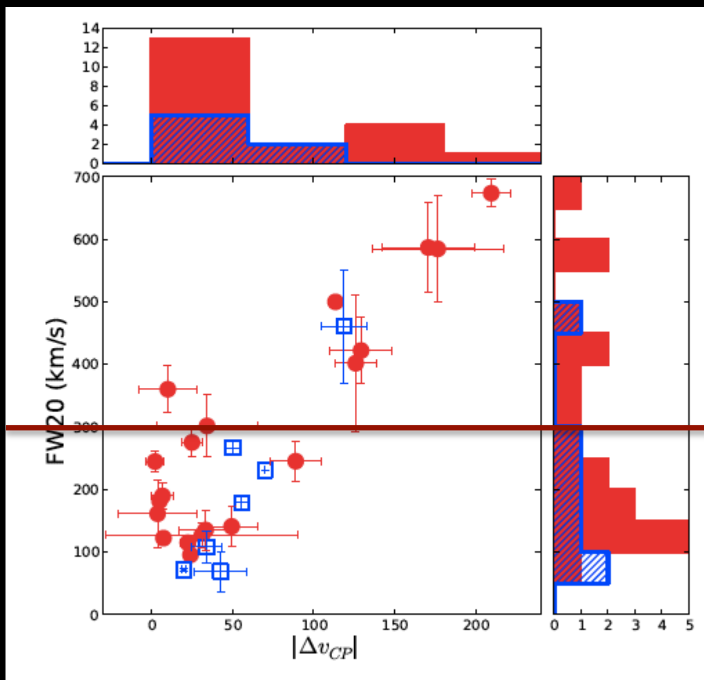


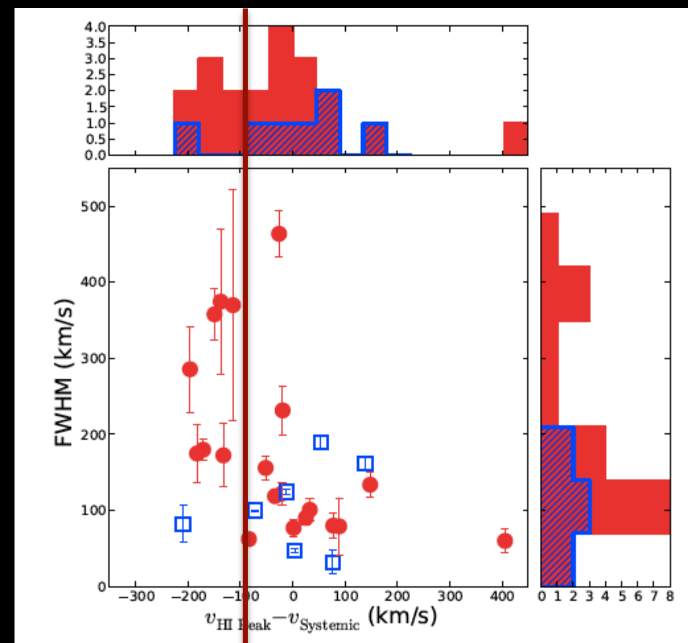
Symmetric broad lines are absent

–> broad profiles are produced by unsettled gas: mergers, outflows

Confirming the stacking results with BF parameters

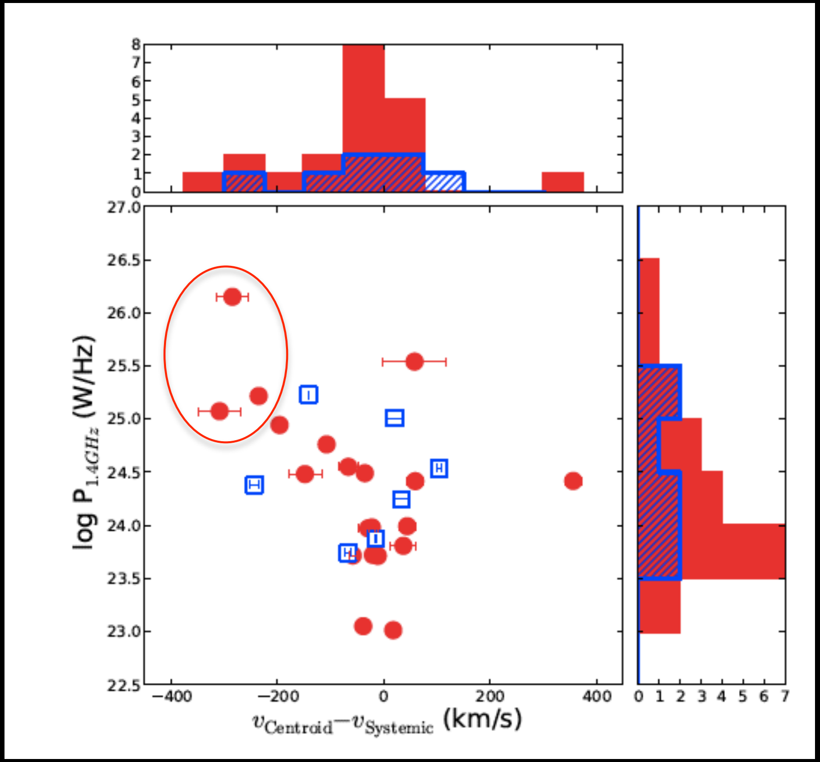
Unsettled gas: traced by large asymmetries and blueshifted / redshifted lines



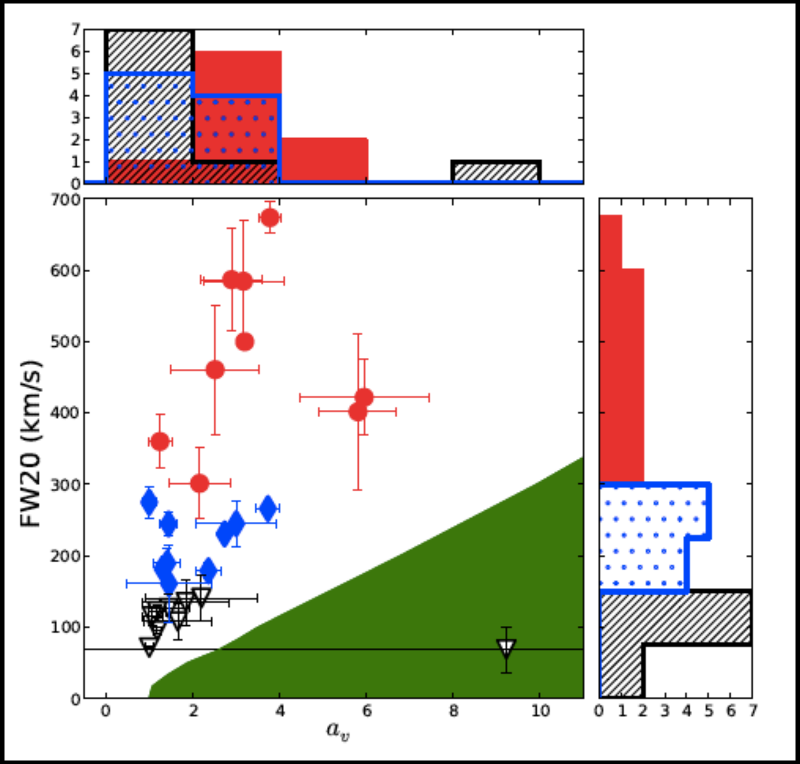


- Compact: rich in unsettled gas, traced by asymmetric, blueshifted lines
- Higher fraction blueshifted than redshifted (*Vermeulen+ 2003, Gupta+ 2006*)

HI outflows

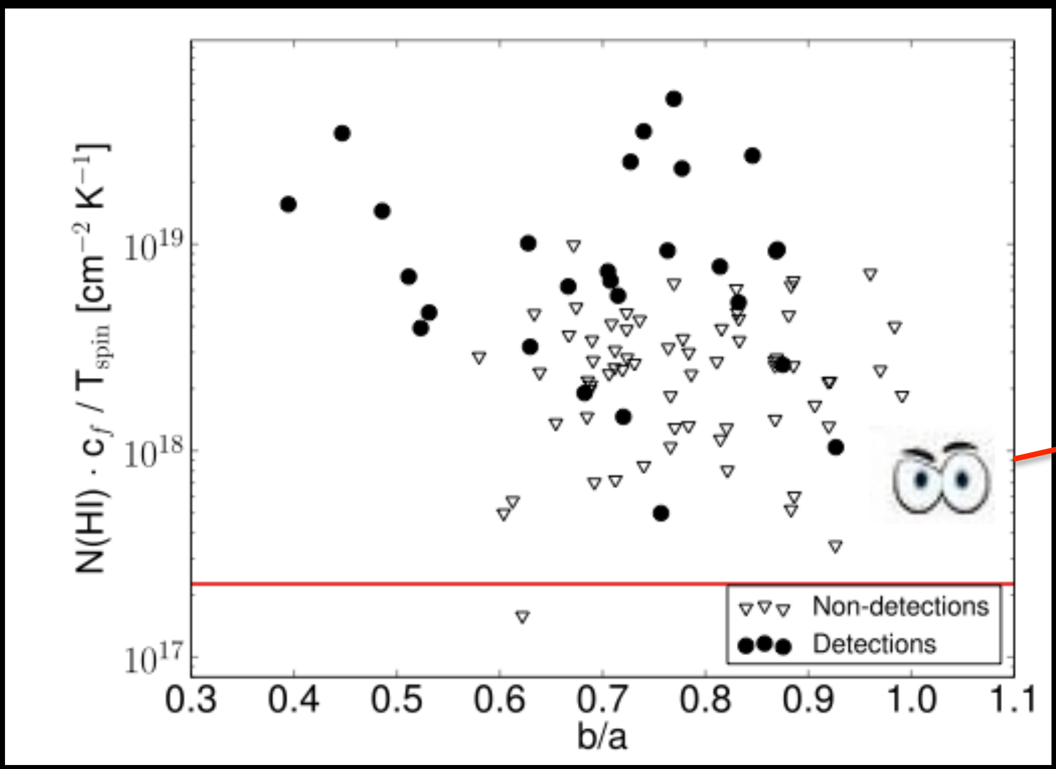


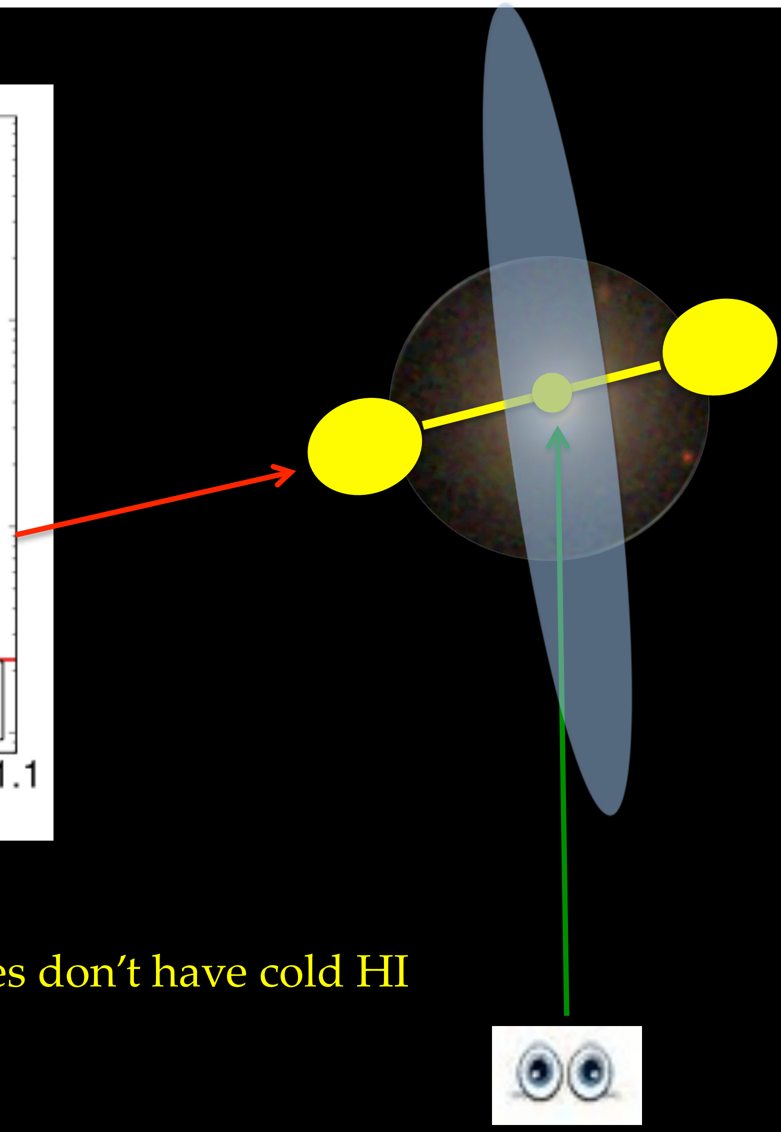
- Jet-cloud interactions in the compact, powerful phase of AGN



$$a_v = \max\left(\frac{v_{\mathrm{FW20}\,R} - v_{\mathrm{HI\ Peak}}}{v_{\mathrm{HI\ Peak}} - v_{\mathrm{FW20}\,B}}, \left(\frac{v_{\mathrm{FW20}\,R} - v_{\mathrm{HI\ Peak}}}{v_{\mathrm{HI\ Peak}} - v_{\mathrm{FW20}\,B}}\right)^{-1}\right),$$

Is the dichotomy due to orientation effects?





- Orientation effects play a role, but some sources don't have cold HI

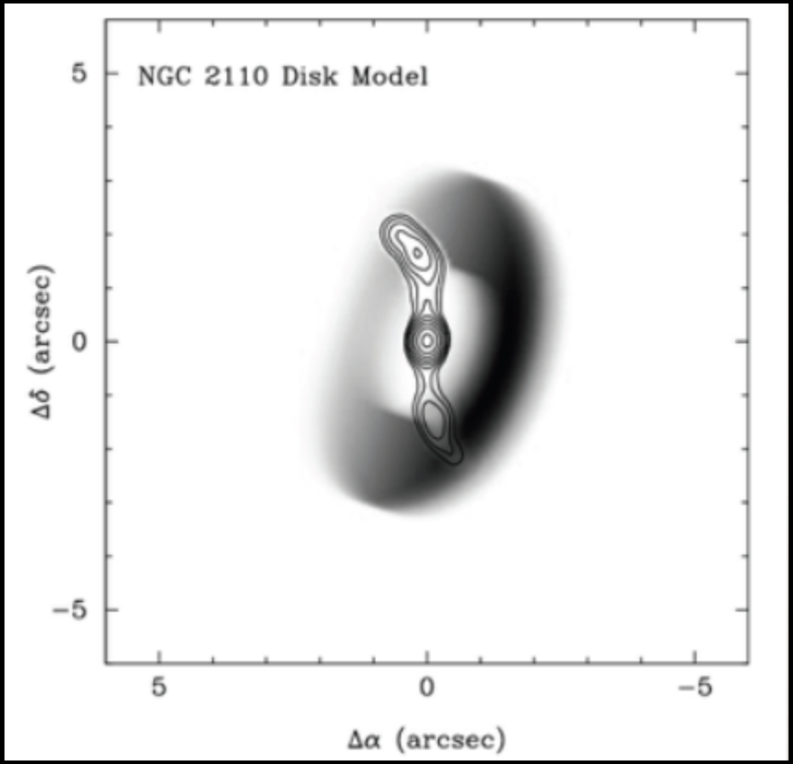
The HI Absorption Safari

F. Maccagni, R. Morganti, T. Oosterloo, K. Gereb, J. Allison

- + 152 sources (121 observed)
- $S_{1.4GHZ} > 30$ mJy
- 15 detections so far

WARNING:

- WSRT less performant (8/14 dishes)
- radio sources less powerful



- Effects of orientation on the morphology of the line
- Can we explain the dichotomy with orientation effects of a disk?

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