UNVEILING THE PHYSICAL CONDITIONS OF NEUTRAL GAS THROUGH RADIO RECOMBINATION LINES

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LEIDEN OBSERVATORY

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HI ABSORPTION 2017
ASTRON

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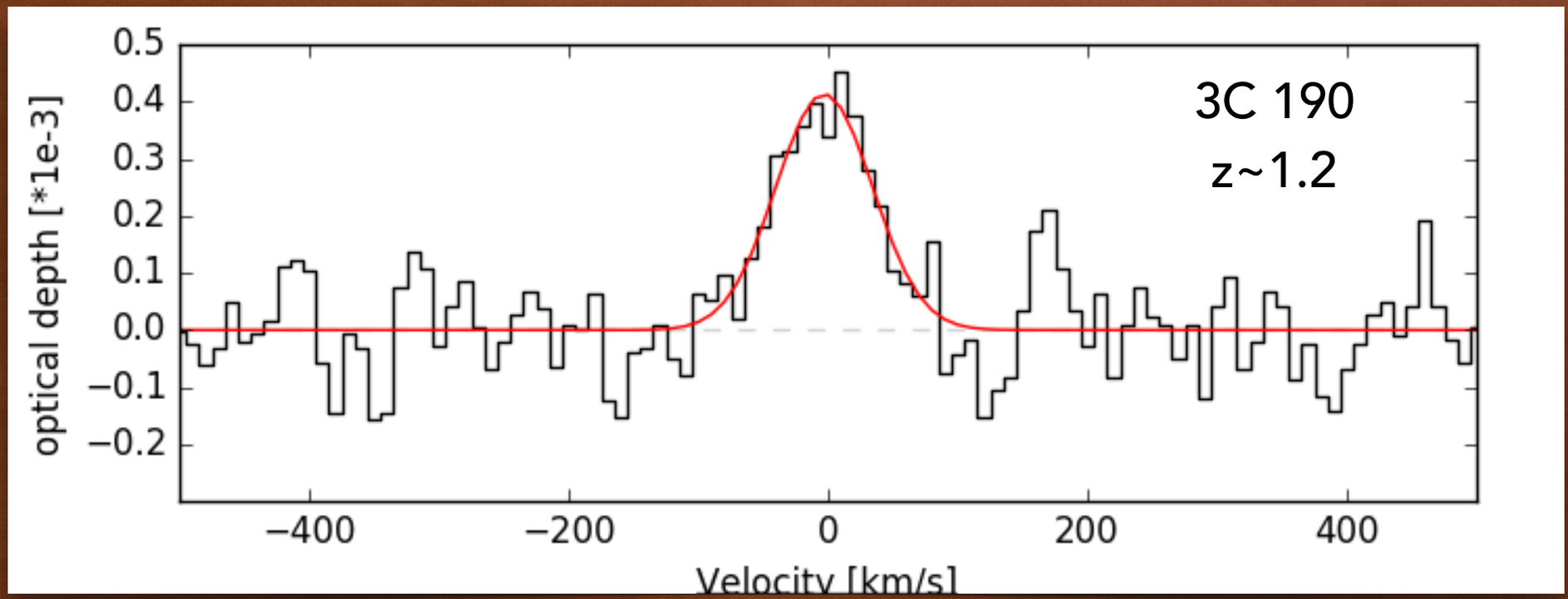

TALK OUTLINE

- What are Carbon RRLs?
- Insight from CRRLs
- Making the detection
- Results on 3C190, 3C293, 4C29.30

RADIO RECOMBINATION LINES

Physical mechanism:

- electron recombination at high quantum levels (n~500)
- low energy transitions (small Δn)

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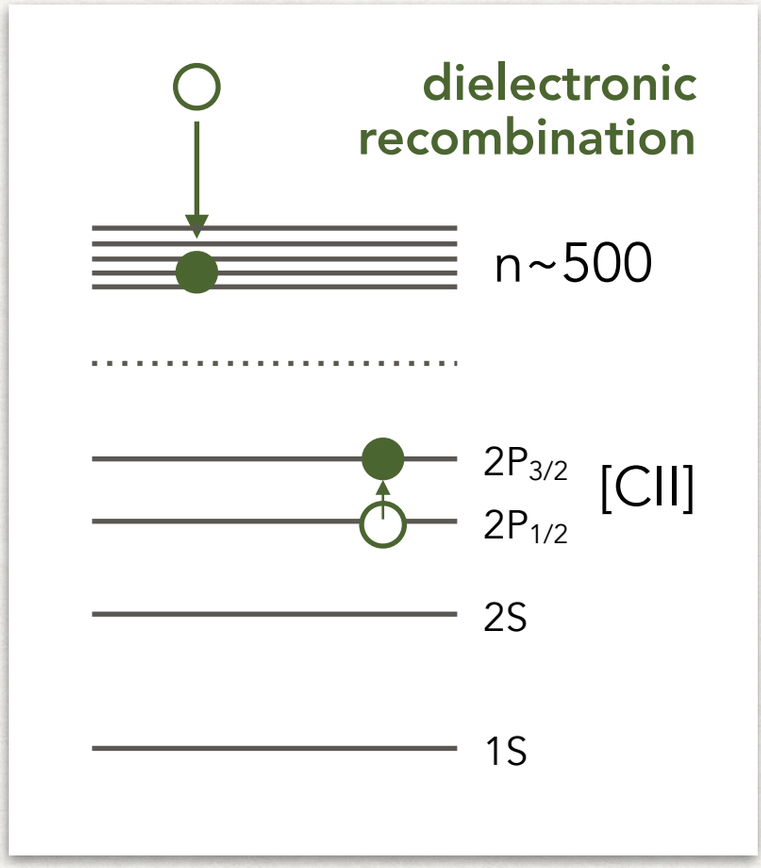


Low frequencies (<500 MHz):

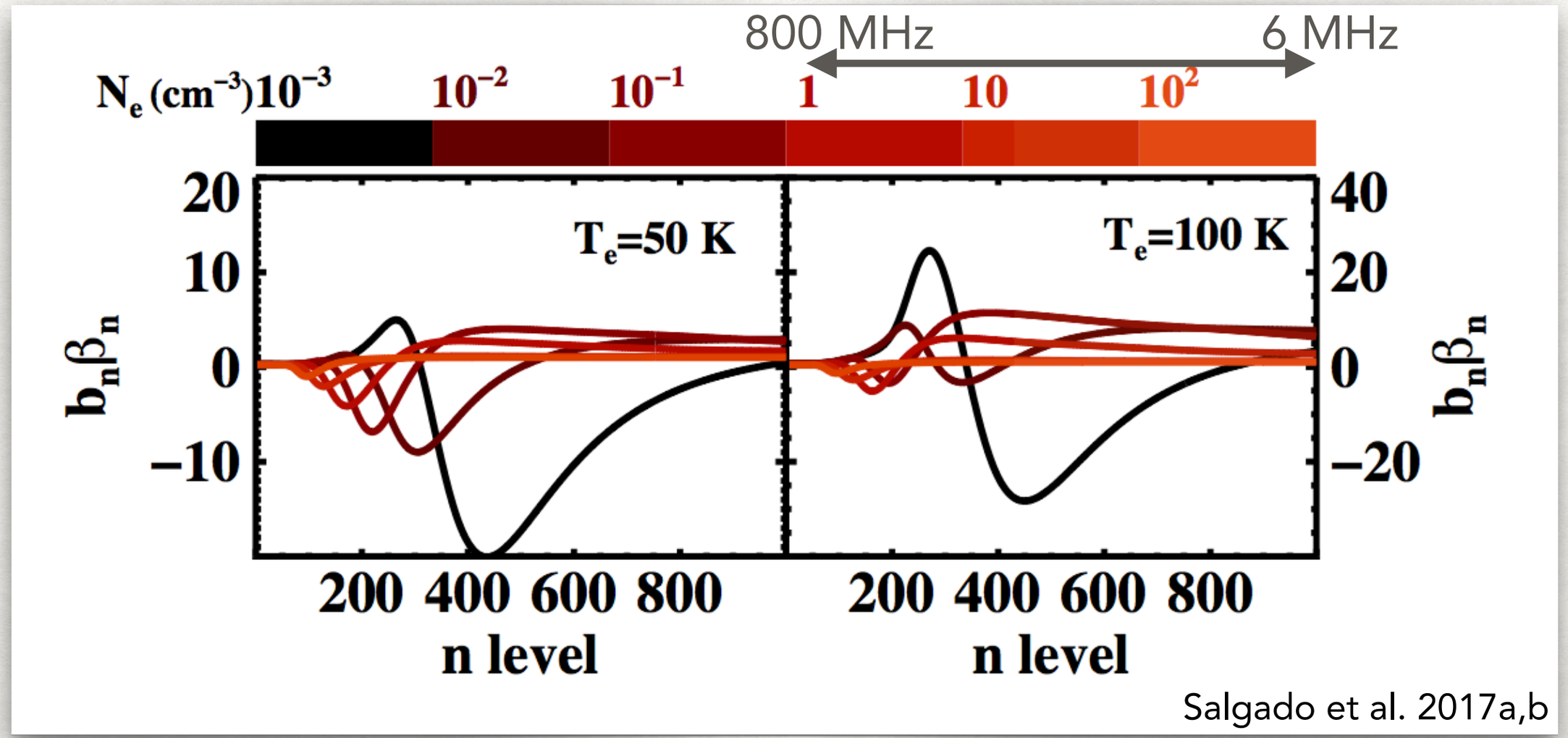
- dielectronic recombination to carbon
- cold (T_e~50–100 K)
  diffuse (n_e~0.01–0.1 cm^{-3})
- purely stimulated, observe to high z

Salgado et al. 2017a,b

OBSERVABLES OF CRRL

- central velocity + spatial resolution
- integrated optical depth
- line profile

$$\int \frac{I_{\rm line}}{I_{\rm cont}} {\rm d}\nu \;\; \propto \;\; -\left(b_n \beta_n\right) T_e^{-5/2} EM_{\rm C+}$$



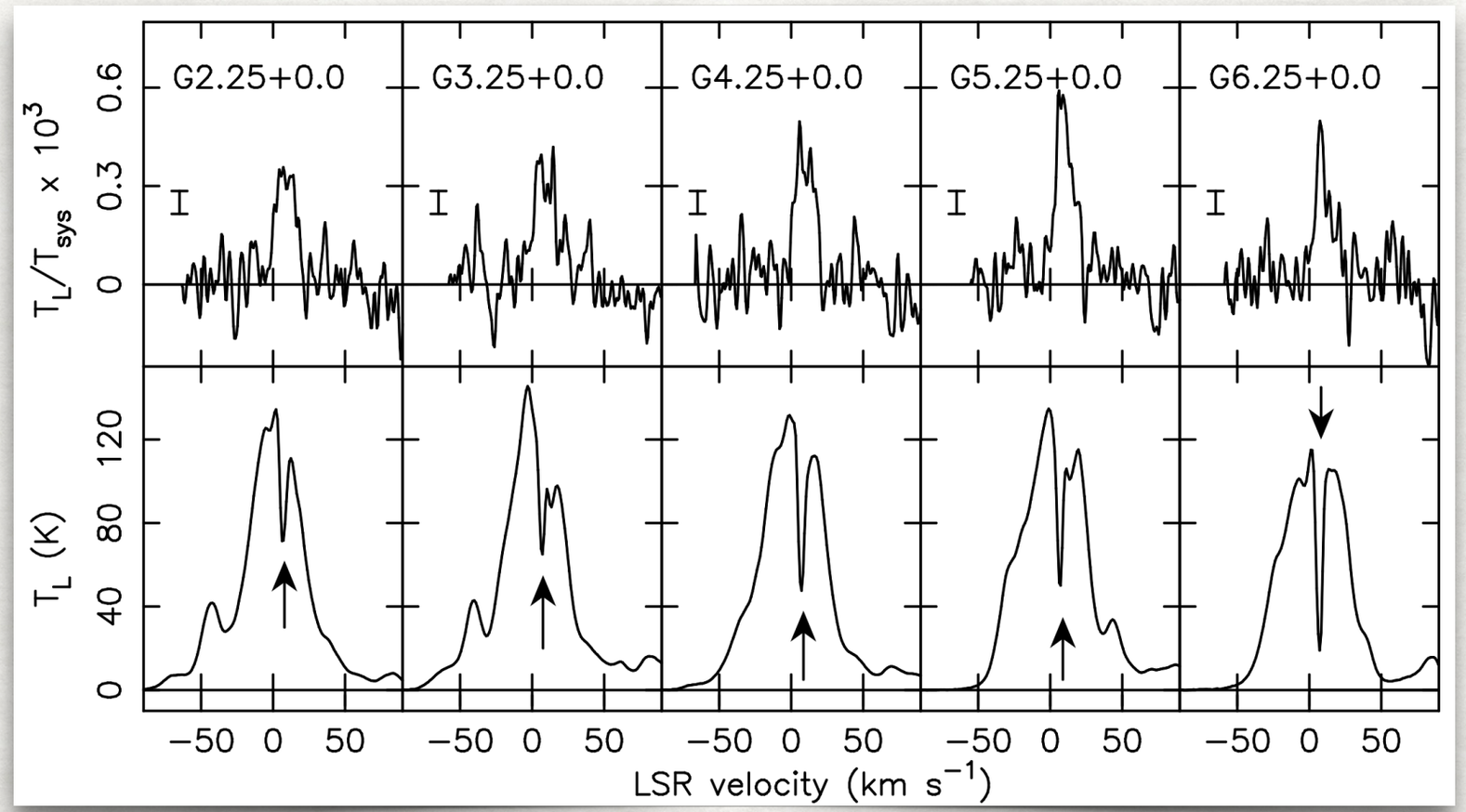
Salgado et al. 2017a,b

KEY INSIGHTS FROM CRRL

1. Detection alone is indicative of CNM gas
2. Probe conditions of gas in AGN environment and/or host galaxy
3. Construct physical model, with properties of atomic gas

SYNERGY WITH HI ABSORPTION

Carbon @
n = 272
327 MHz

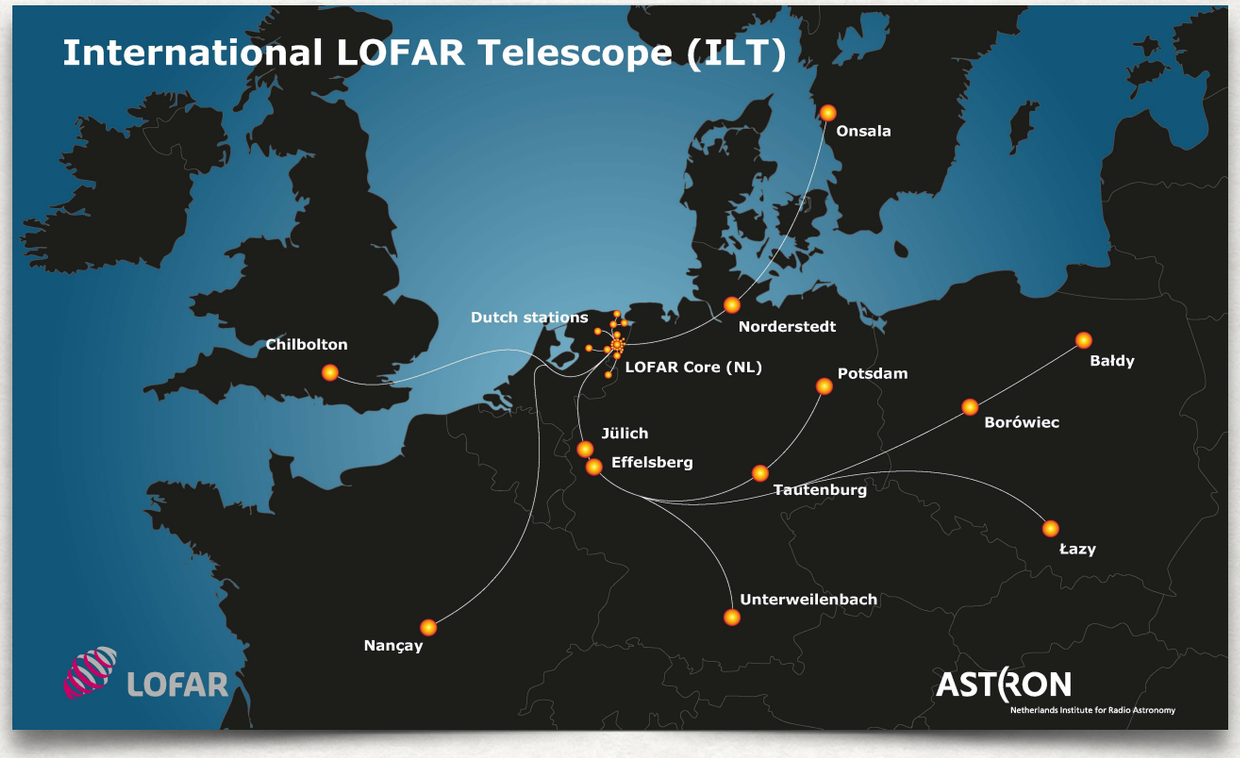


HI taken from
LAB survey
Kalbera et al. 2005

Roshi & Kantharia 2011

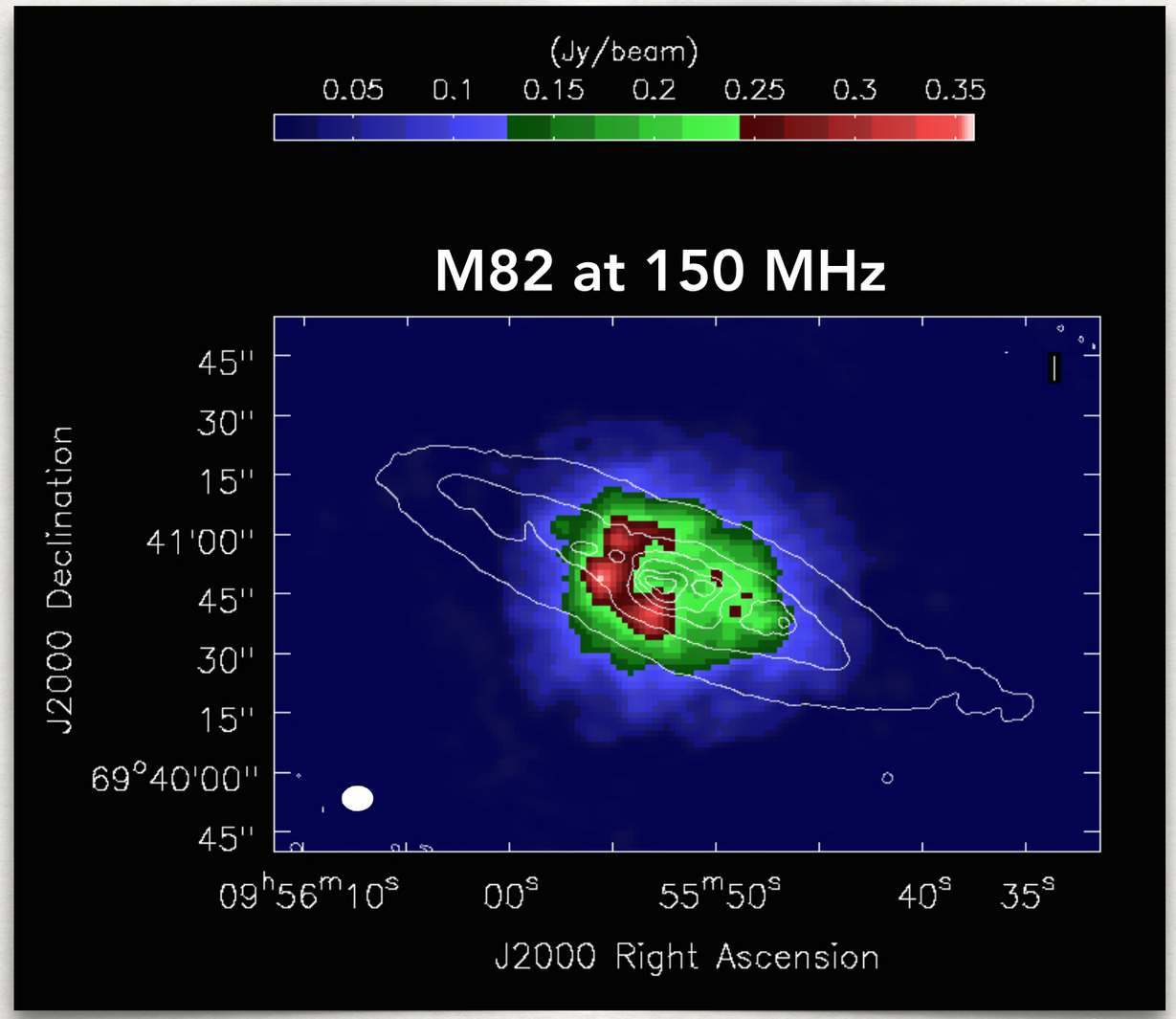
DETECTING EXTRAGALACTIC CRRL

- frequencies < 500 MHz
- peak optical depths ~10^{-3} — 10^{-4}
- detections now possible
  - **wide bandwidth**
  - sensitivity
  - high resolution

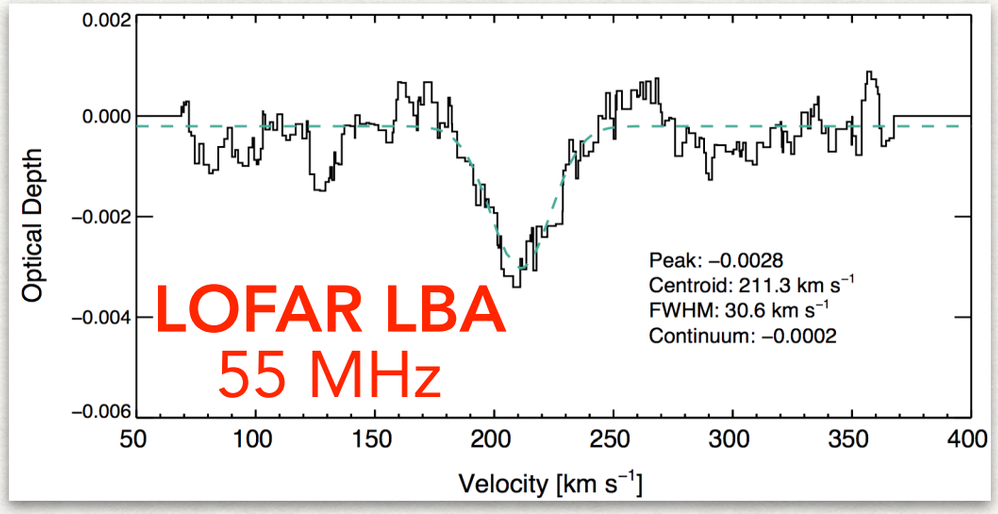


LOFAR DETECTIONS IN M82

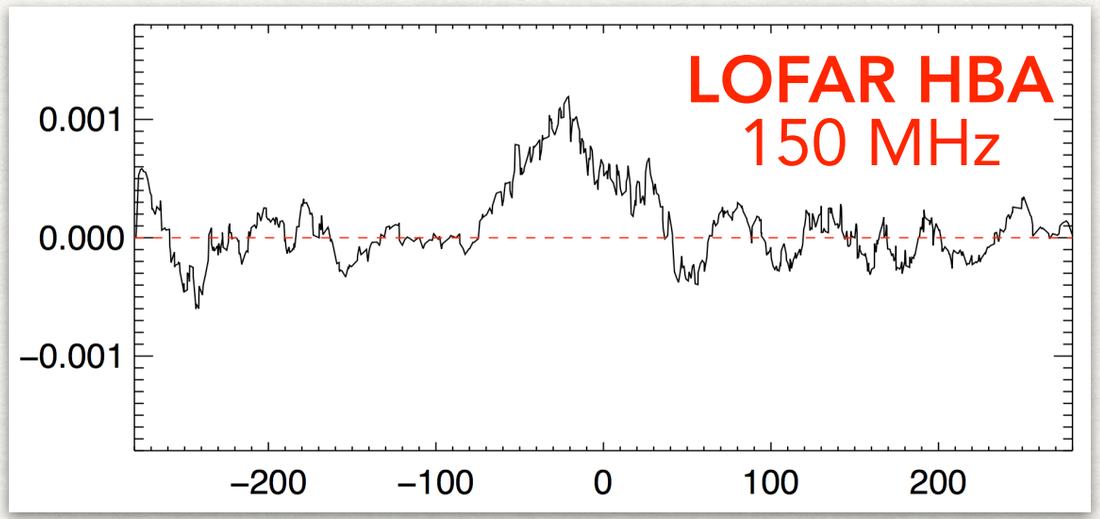
M 82
STARBURST
4 MPC AWAY
BRIGHT
WELL-STUDIED



courtesy MC. Toribio



L. Morabito et al. 2014

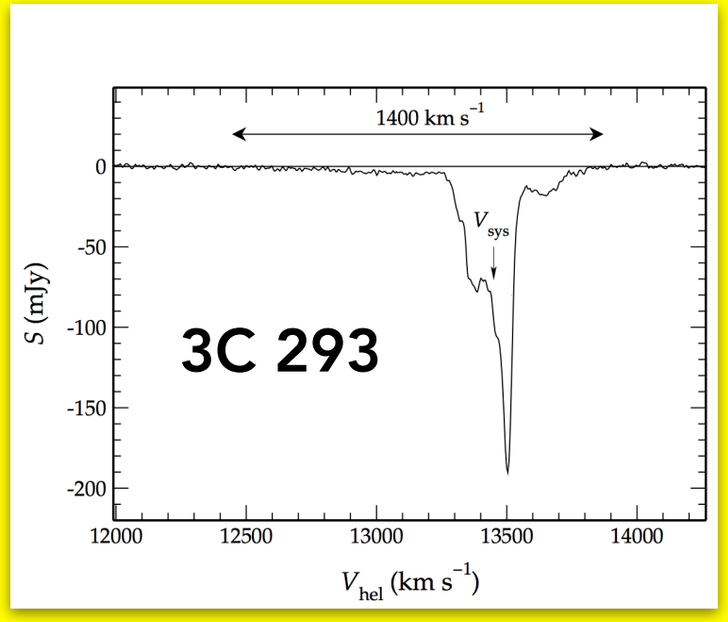


MC. Toribio in prep.

CRRL AT COSMOLOGICAL DISTANCES

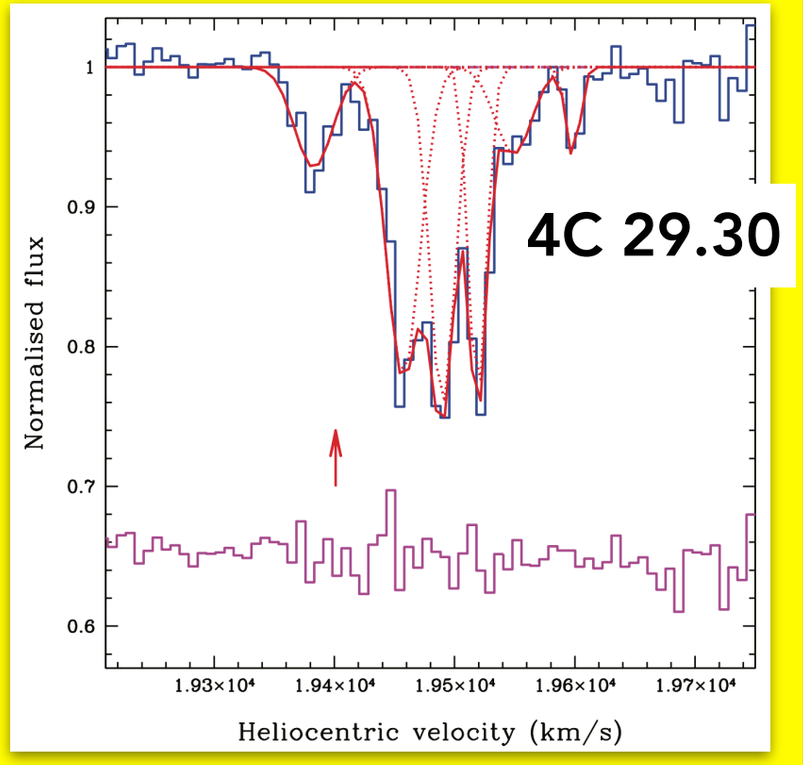
- bright
- HI absorber
- compact
- steep spectrum

Emonts et al. 2005

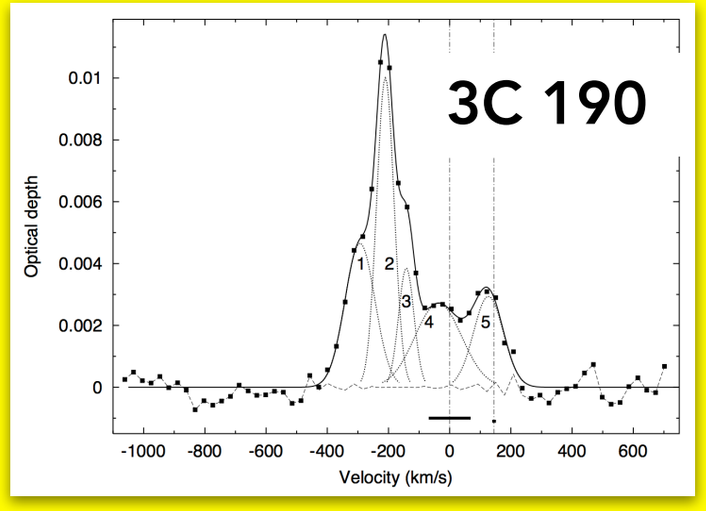


LOFAR HBA OBSERVATIONS
PI: M. BRIENZA

Chandola et al. 2010



Ishwara-Chandra et al. 2003



3C 190
LOFAR HBA + LBA
PI: K. EMIG

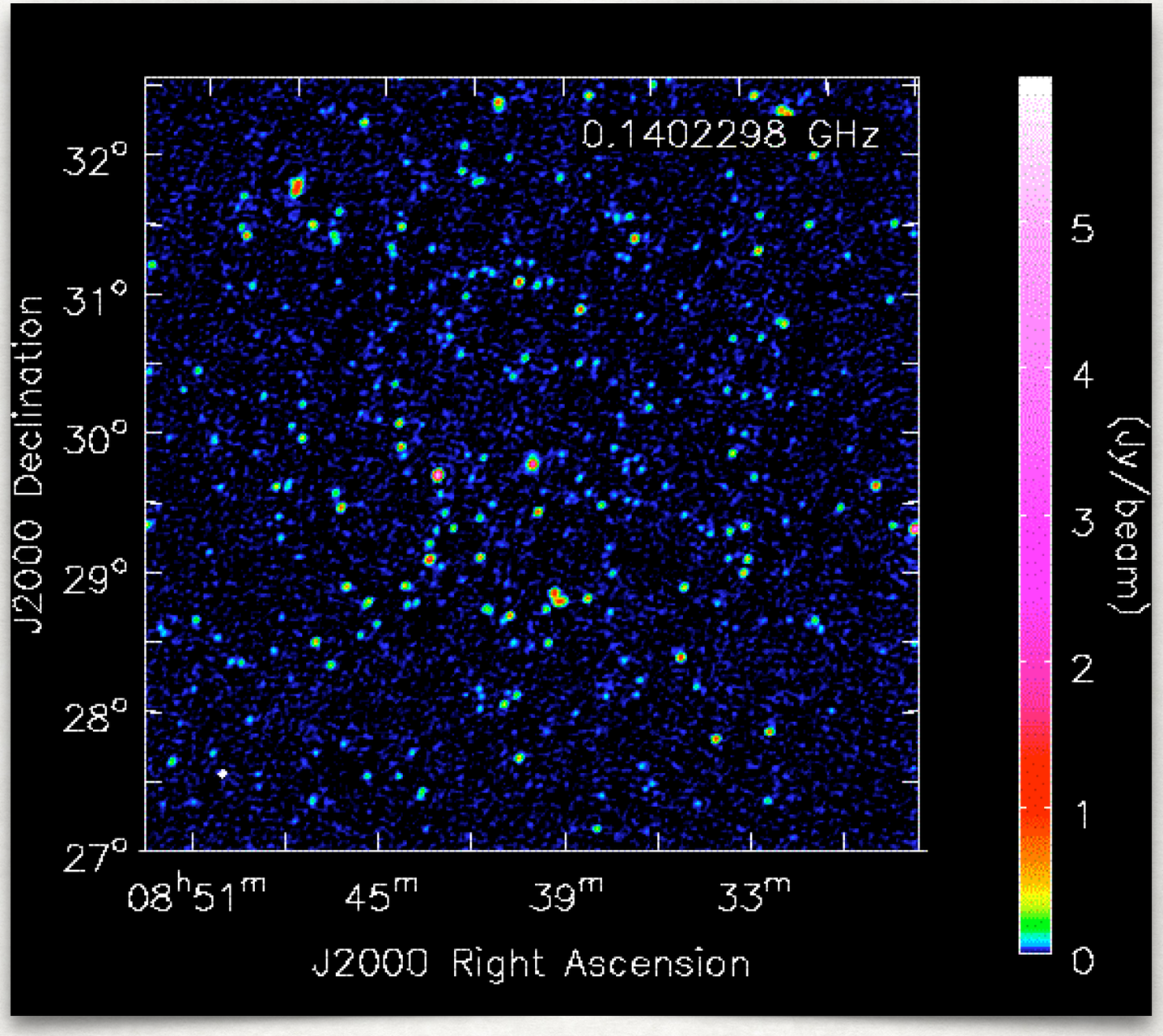
DATA PROCESSING

About pipeline

- LOFAR core stations
  - same ionosphere
  - resolution ~2arcmin
- direction-independent
- channel images 2-3x thermal noise
- spectral rms 10^{-3}

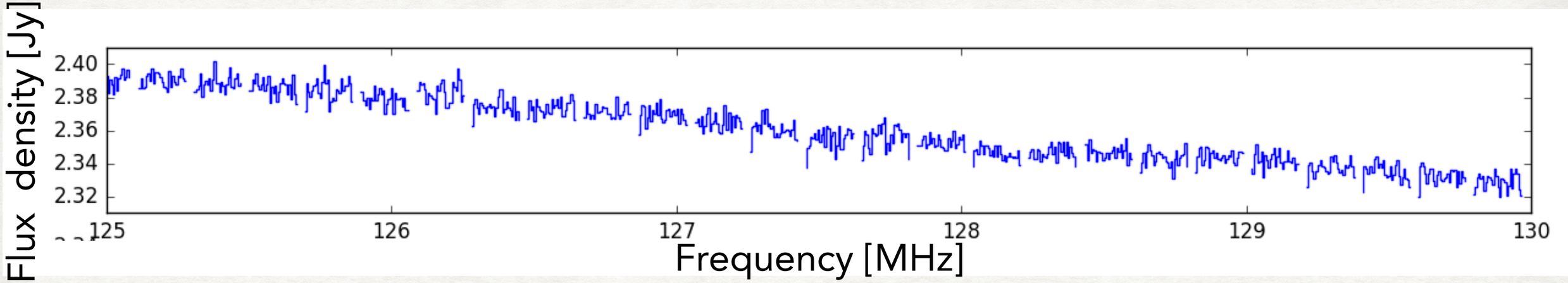
Essential for processing

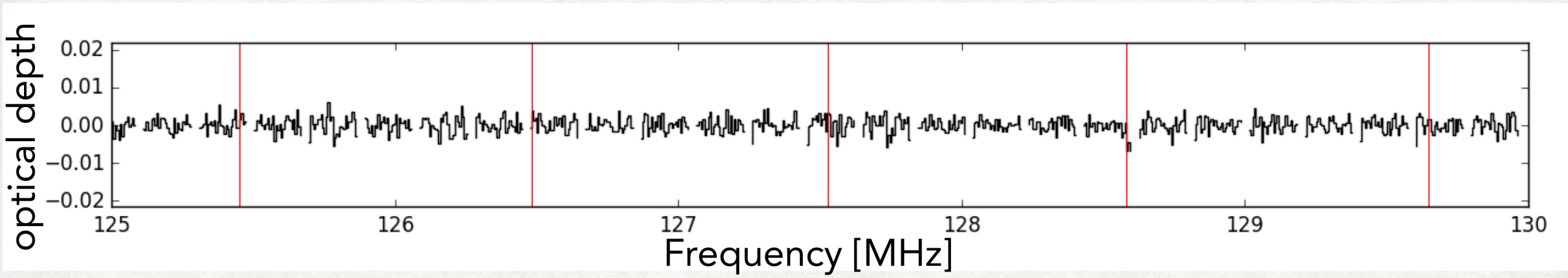
- SURFSara NL grid
  - ~few days processing
- software available



CHANNEL IMAGE
10 MJY/BEAM
3X THERMAL NOISE

SPECTRAL PROCESSING

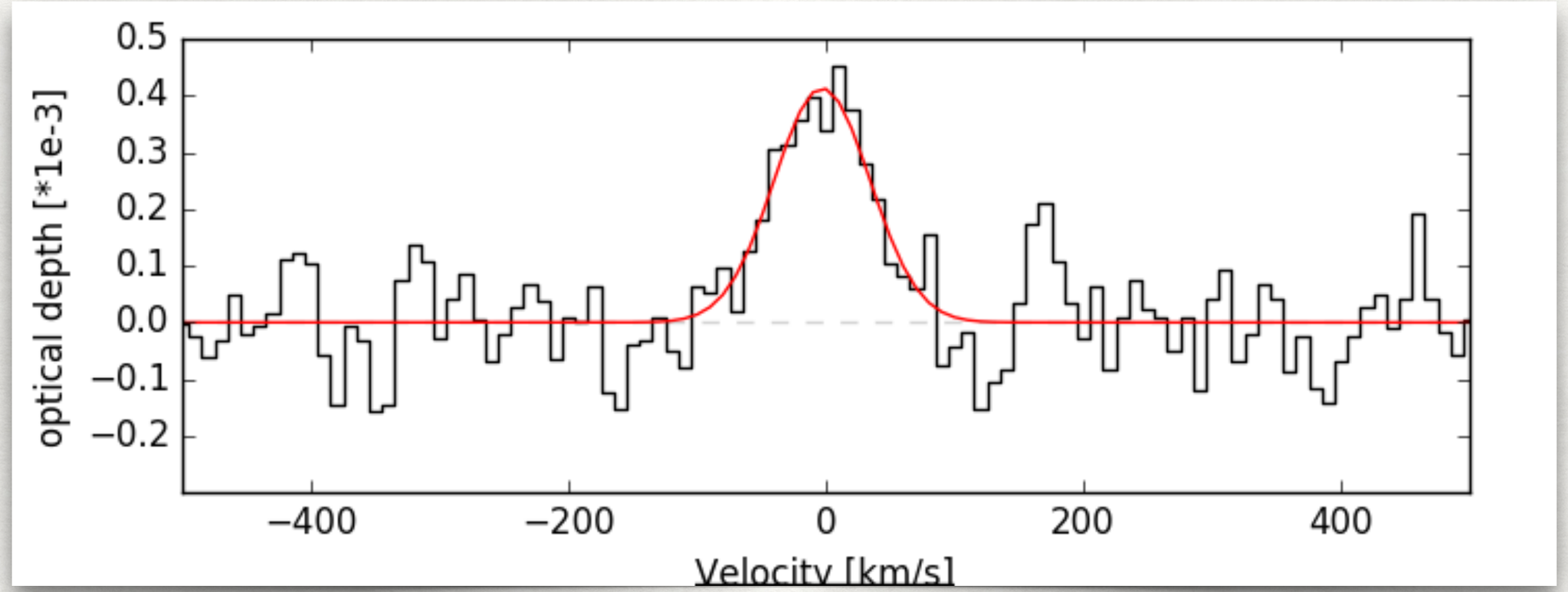




typically ~30 lines between 120-160 MHz

~20 lines with RFI and lines falling on channel edge

3C 190 DETECTION



S(150 MHz) ~ 20 Jy

16 lines

stack center, z = 1.196

Δv = 88 km/s

effective frequency = 133 MHz

effective quantum number, n = 287

3C 190

- z_{opt} = 1.195
- in-falling foreground absorber
- resolved at 2″ (22 kpc)
- HI from jet interaction
- core self-absorbed < 600 MHz

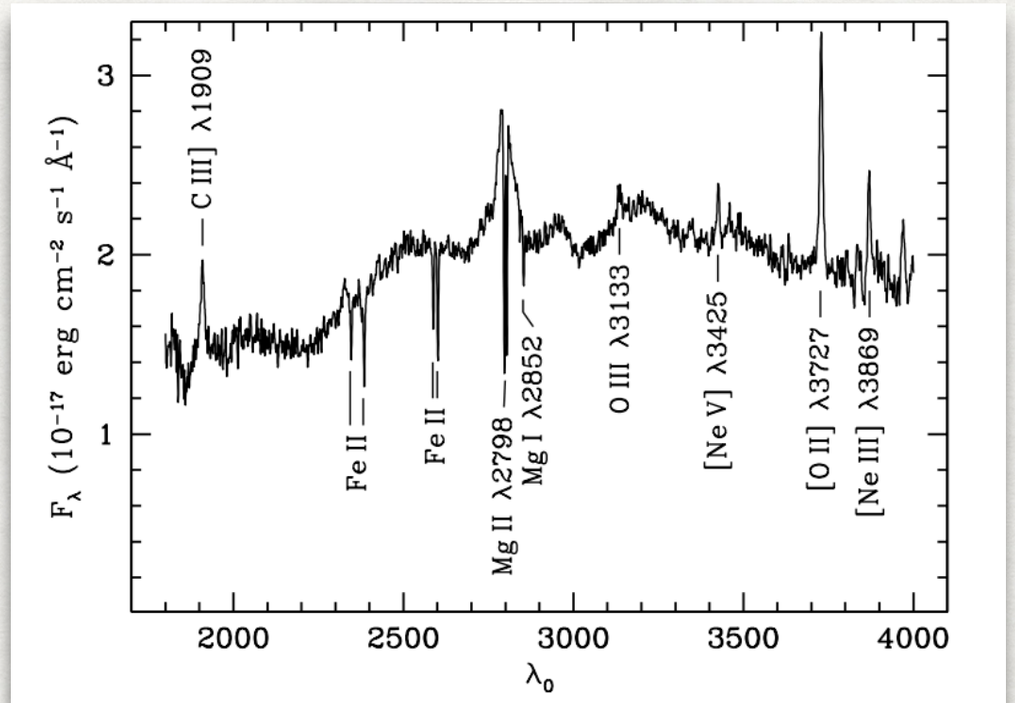
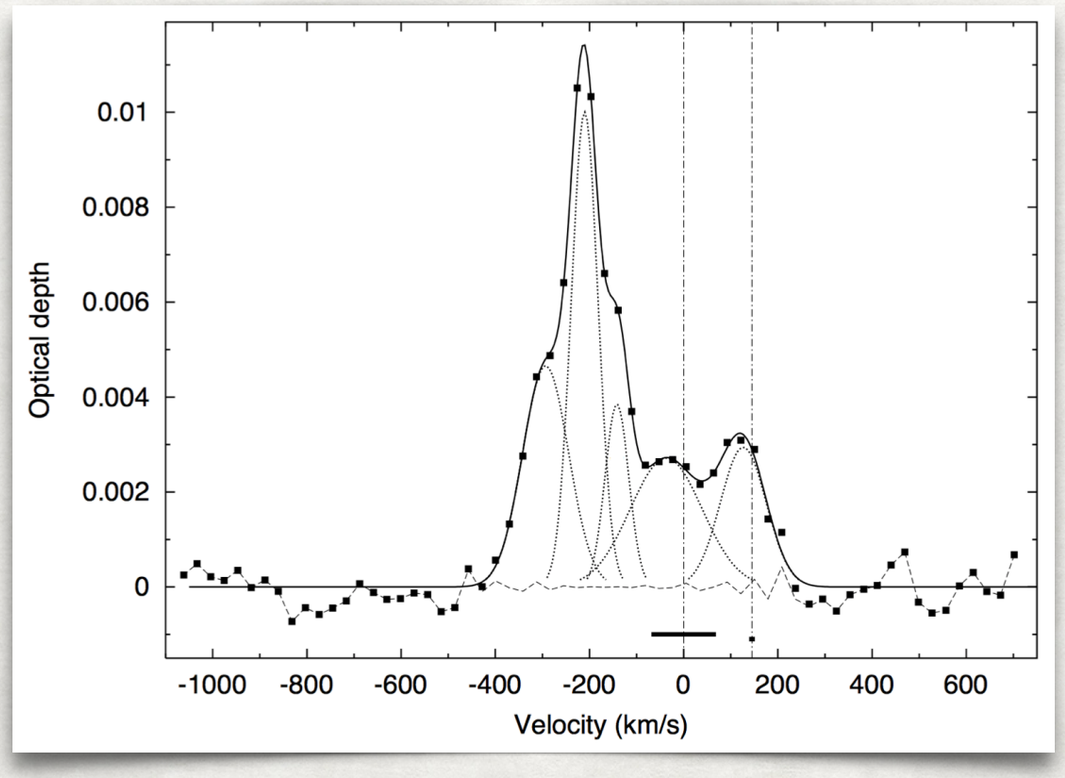


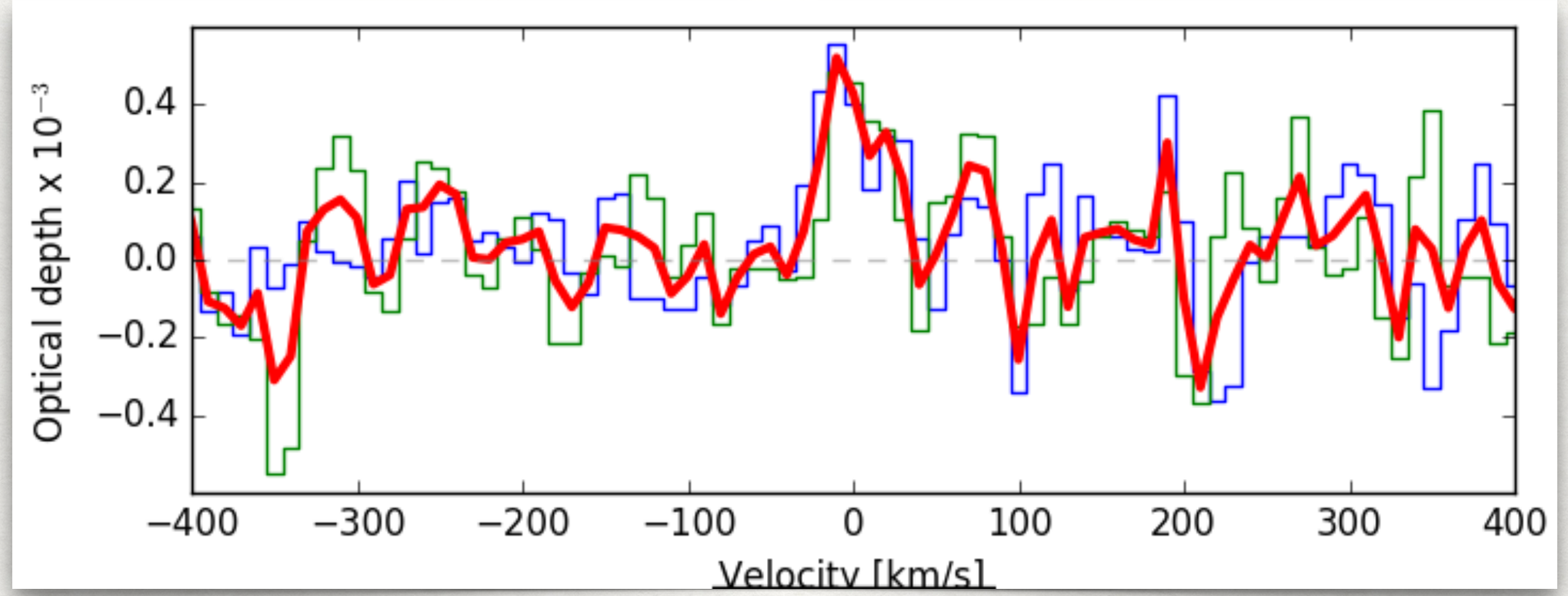
FIG. 4.—Spectrum of 3C 190 (the quasar itself). The absorption lines all appear to come from a single system close to the quasar redshift.

Infalling foreground absorber
at z = 1.196
Stockton & Ridgway 2001



HI absorption blue shifted,
outflow from jet
Ishwara-Chandra et al. 2003

3C 293 DETECTION

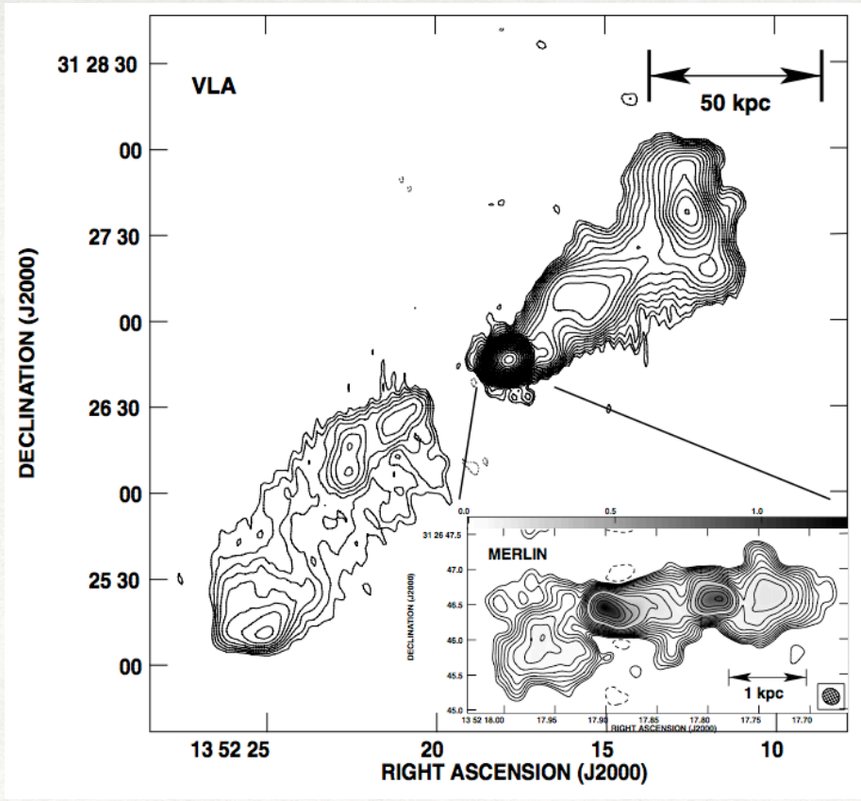


S(150 MHz) ~ 15 Jy
12 lines
stack center, z = 0.045
Δv = 40 km/s
effective frequency = 127 MHz
effective quantum number, n = 371

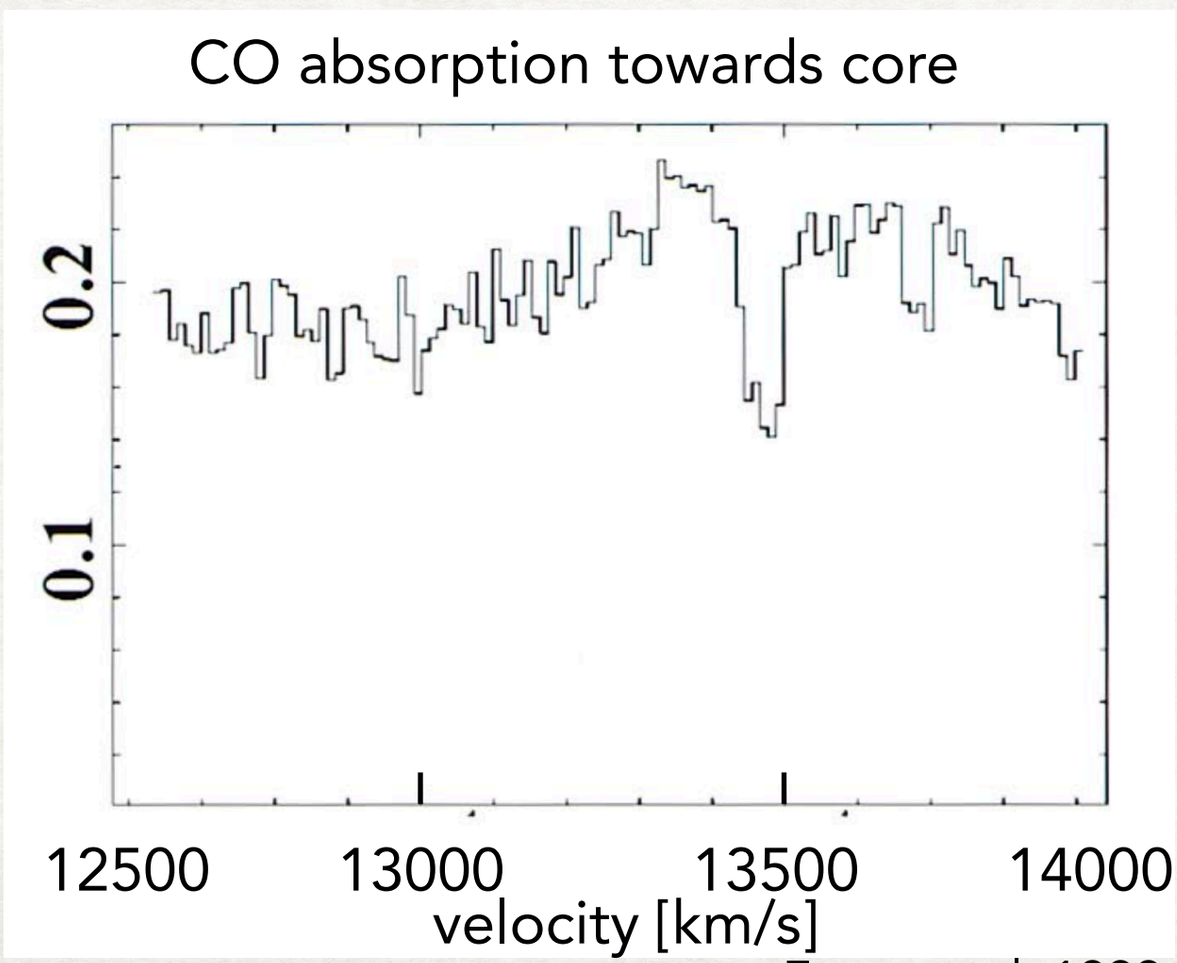
confirmed with
two observations
blue = 4 hr
green = 2.5 hr

3C 293

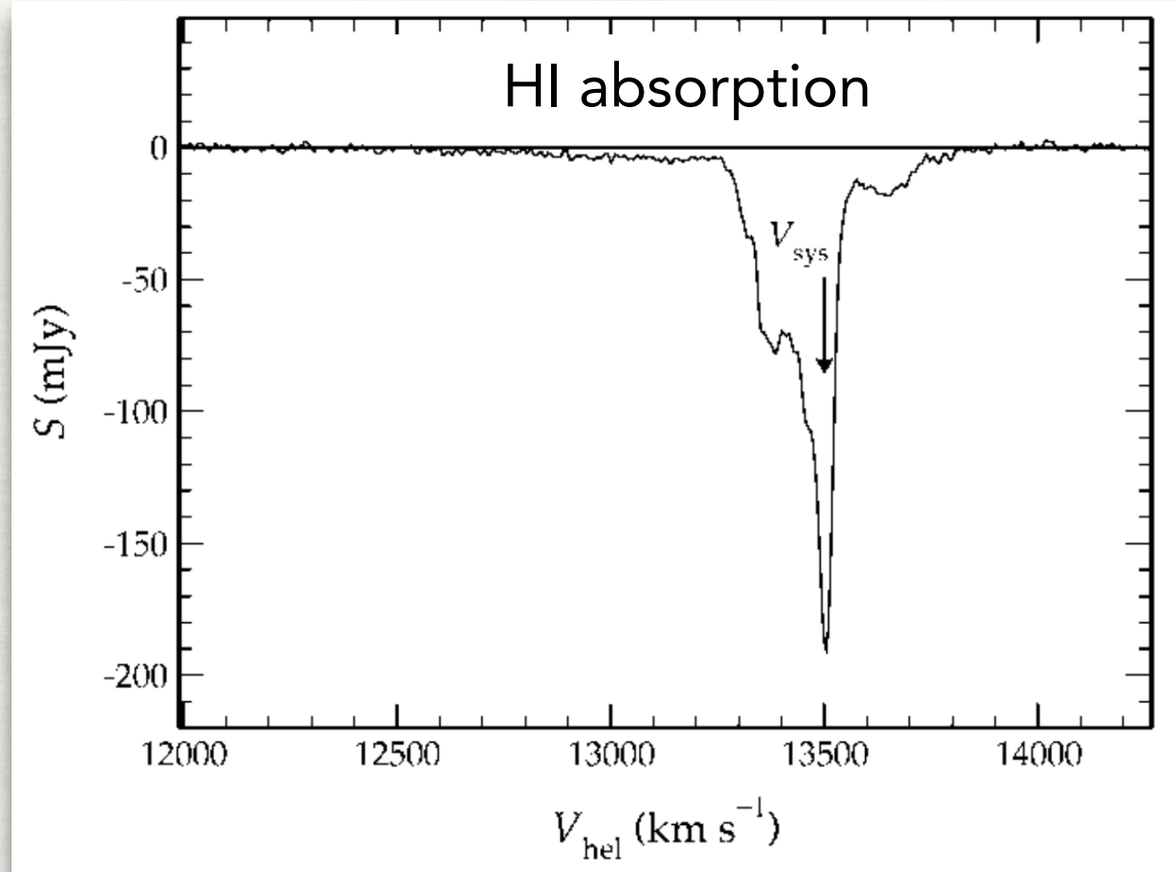
- z_{opt} = 0.045
- HI absorption, Δv ~ 40 km/s
- CO absorption, Δv ~ 40 km/s



Beswick et al. 2004



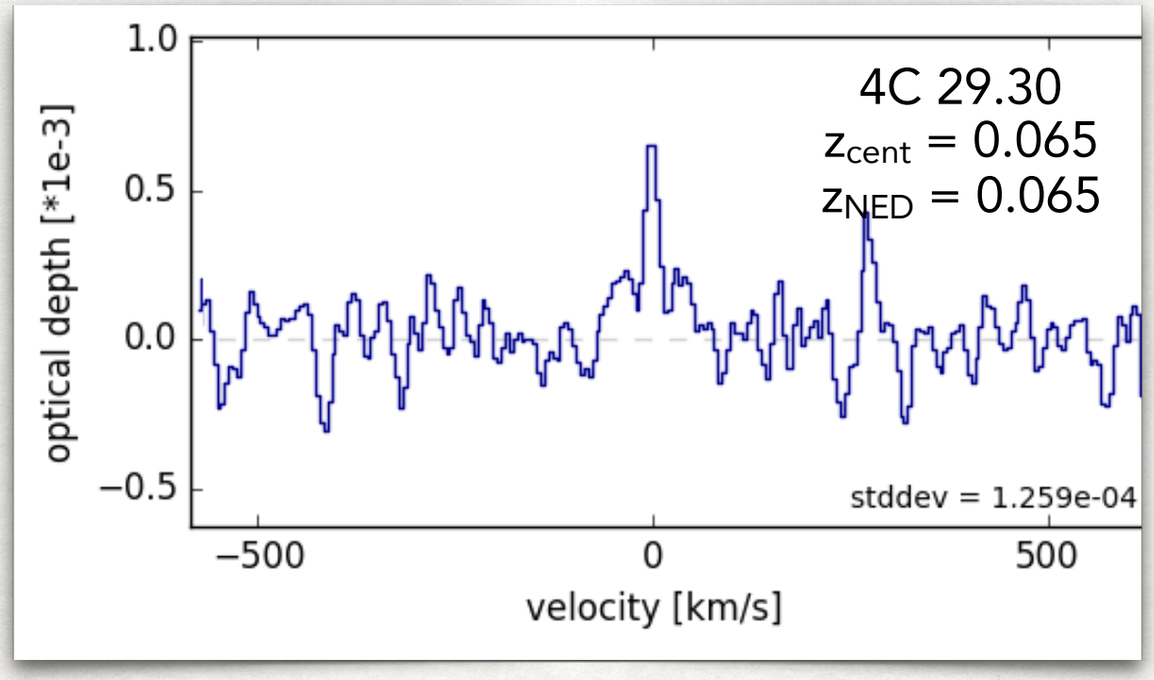
Evans et al. 1999

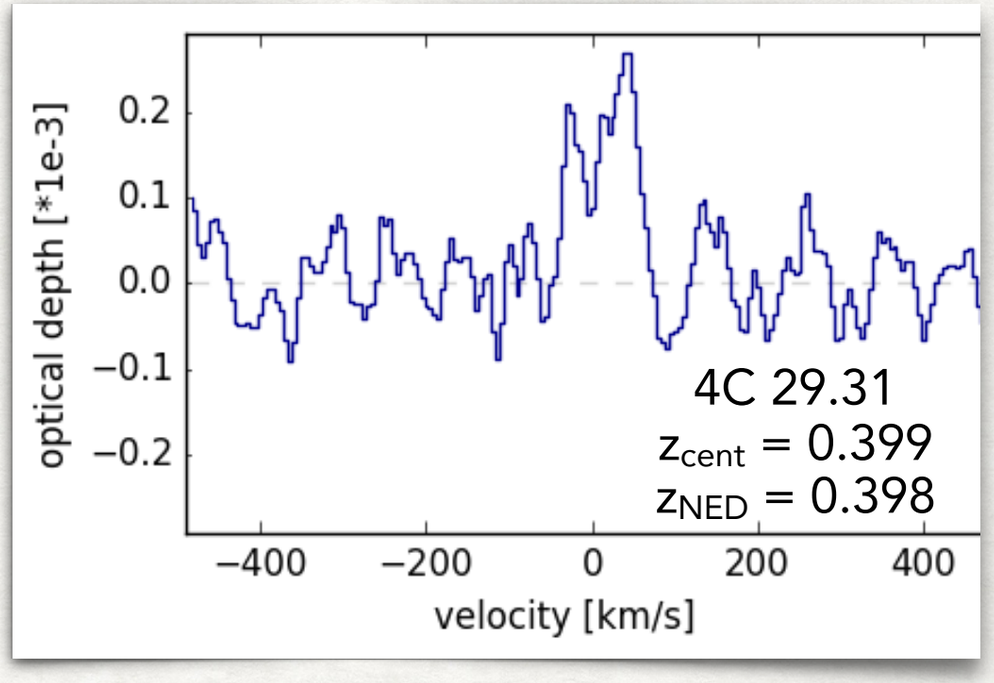


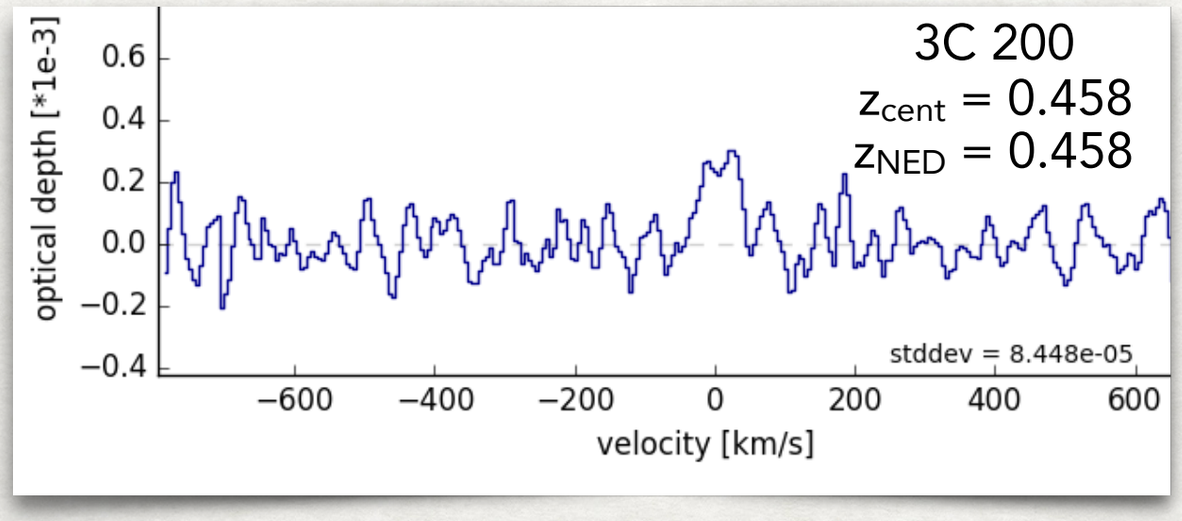
Emonts et al. 2005

4C 29.30 FIELD

PRELIMINARY !!







NEXT STEPS FOR EXTRA-GAL CRRL

1. Is it possible?
2. Single object detections
3. Fields / sample
4. Follow up observations
5. LOFAR Tier 1 Survey of Northern Sky

TAKE AWAY MESSAGES

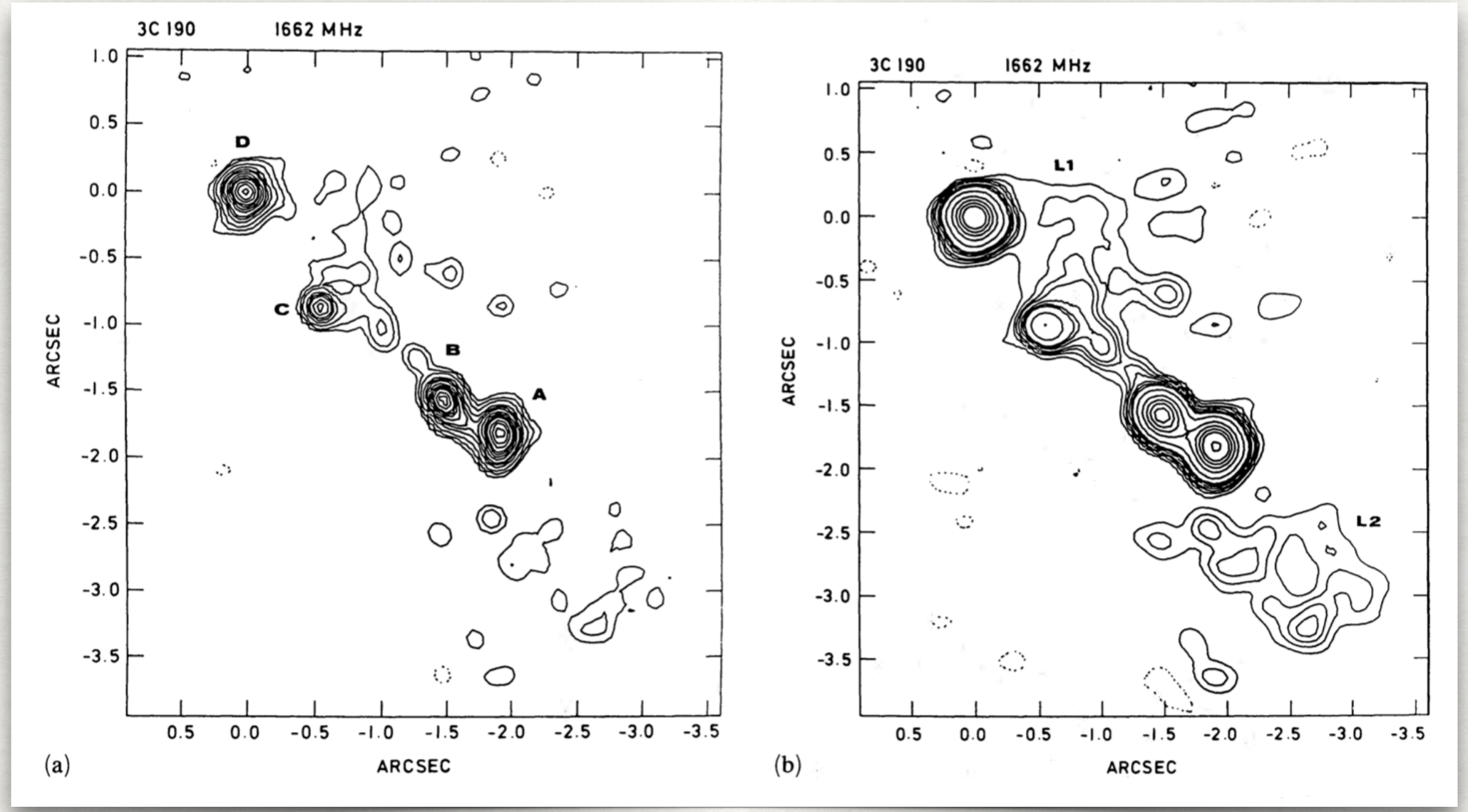
- CRRL can be complimentary + independent tracer of HI absorbing gas, providing physical conditions

- CRRL as probe of CNM in AGN has promising outlook
  - first objects we searched we have detections
  - can extend to high z

NEXT TARGETS

3C 216
3C 236
3C 268.3
3C 305
4C 12.50 ..
4C 26.42
4C 55.16
B2 0902+34

3C 190


3C 190
1662 MHz
D
C
B
A
ARCSEC
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
0.5 0.0 -0.5 -1.0 -1.5 -2.0 -2.5 -3.0 -3.5
ARCSEC
(a)
3C 190
1662 MHz
L1
L2
ARCSEC
(b)