THE FIRST DETECTIONS OF RADIO RECOMBINATION LINES AT COSMOLOGICAL DISTANCES

KIMBERLY EMIG

LEIDEN OBSERVATORY

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HUUB ROTTGERING, XANDER TIELENS

BROAD IMPACT OF
LOW FREQUENCY OBSERVING

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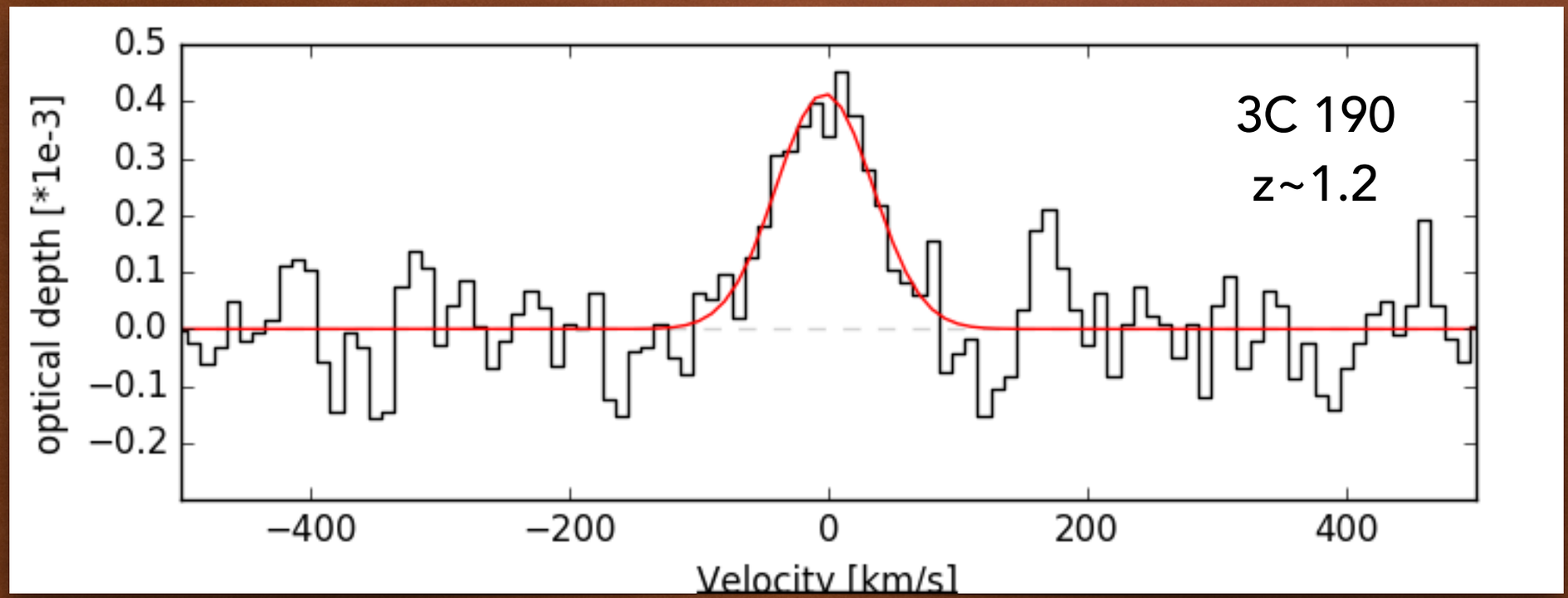

RADIO RECOMBINATION LINES

Physical mechanism:

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

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Low frequencies (<500 MHz):

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

e.g. see Salgado et al. 2017a,b; Shaver 1978

OBSERVABLES OF CRRL

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

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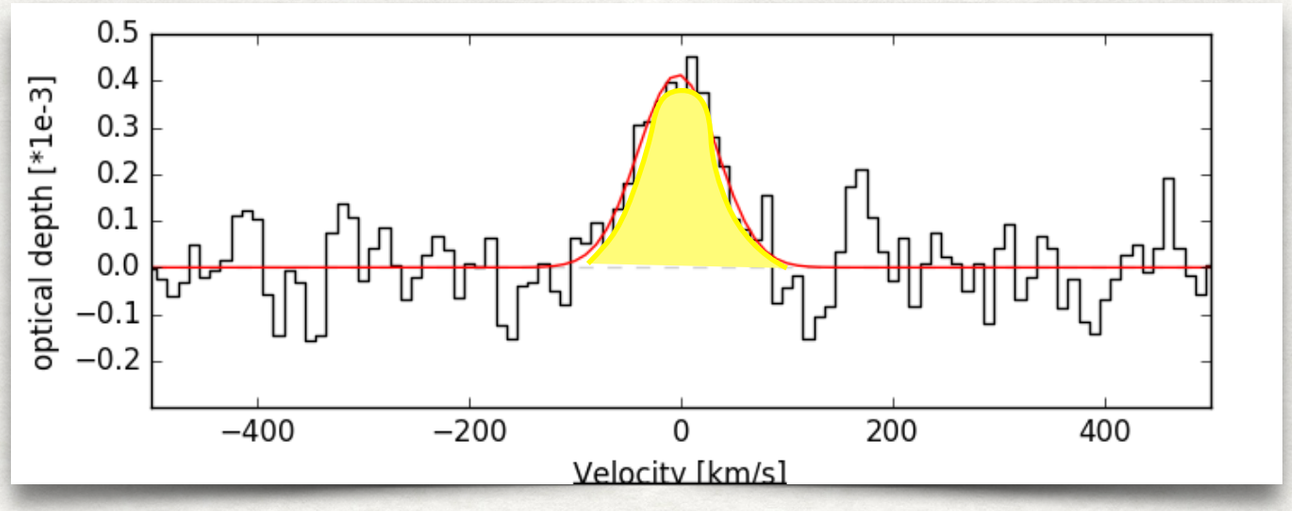

OBSERVABLES OF CRRL

- line profile
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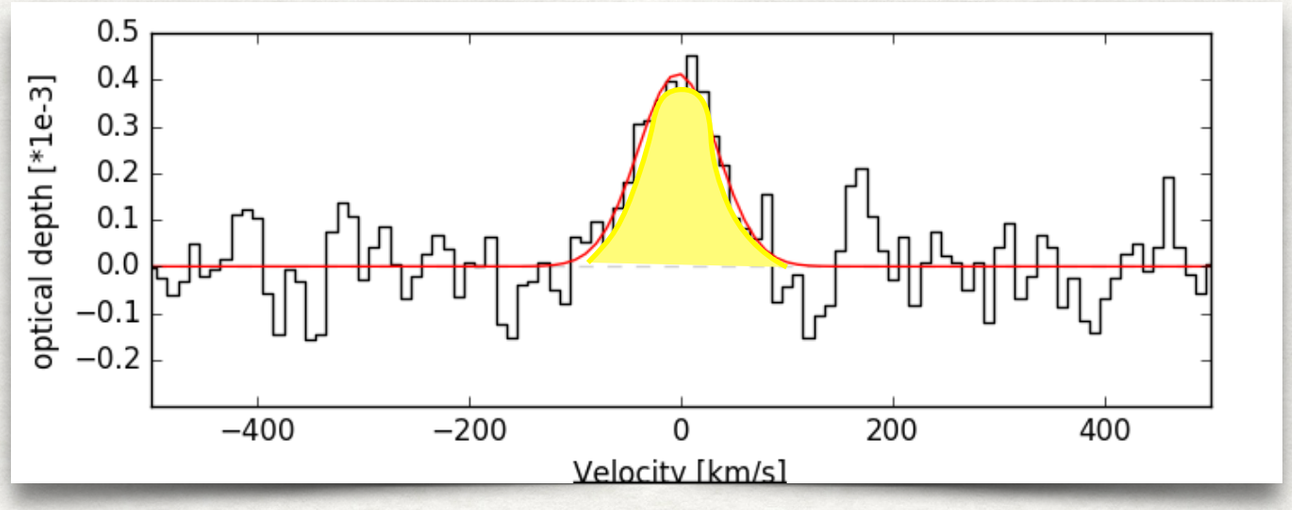
$$\int \frac{I_{\rm line}}{I_{\rm cont}} {\rm d}\nu \;\propto\; -(b_n \beta_n) T_e^{-5/2} n_e^2 \, l$$



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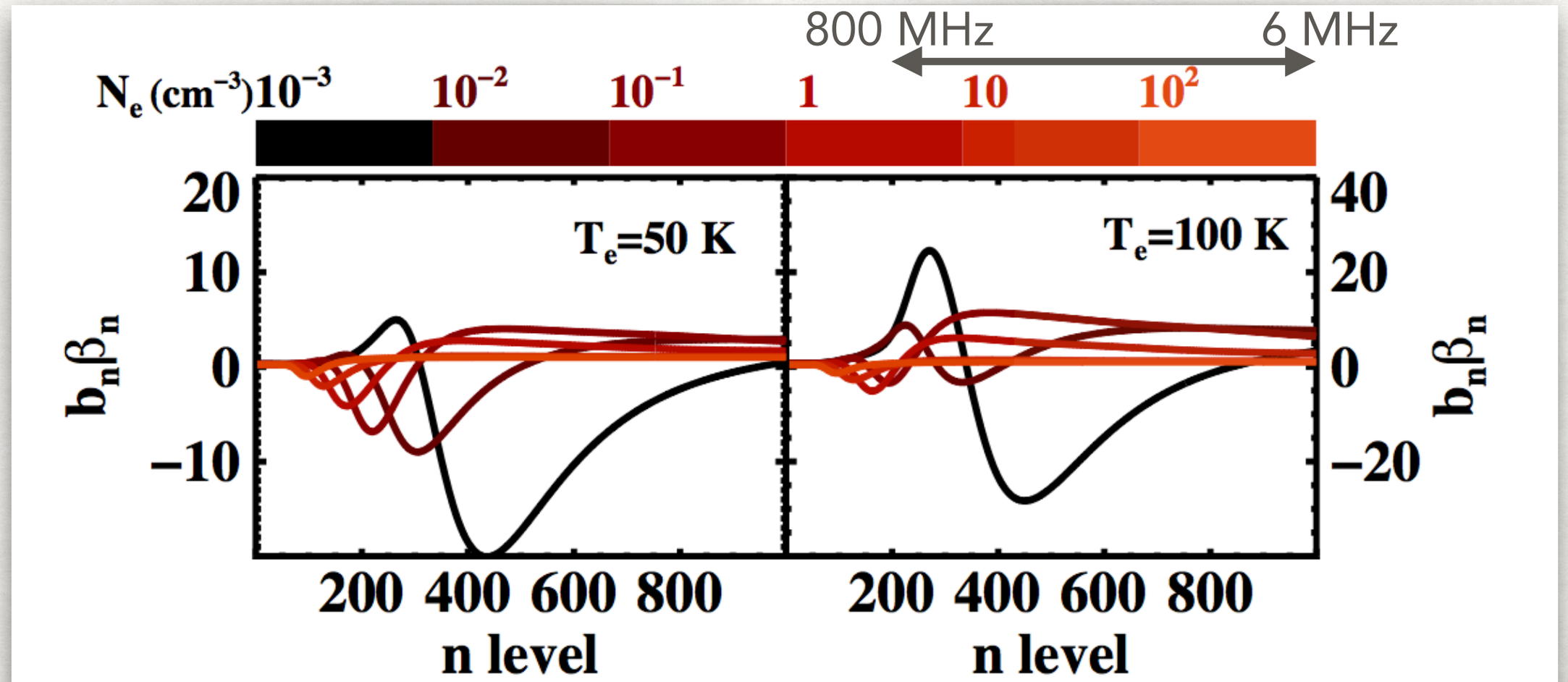

Salgado et al. 2017a,b

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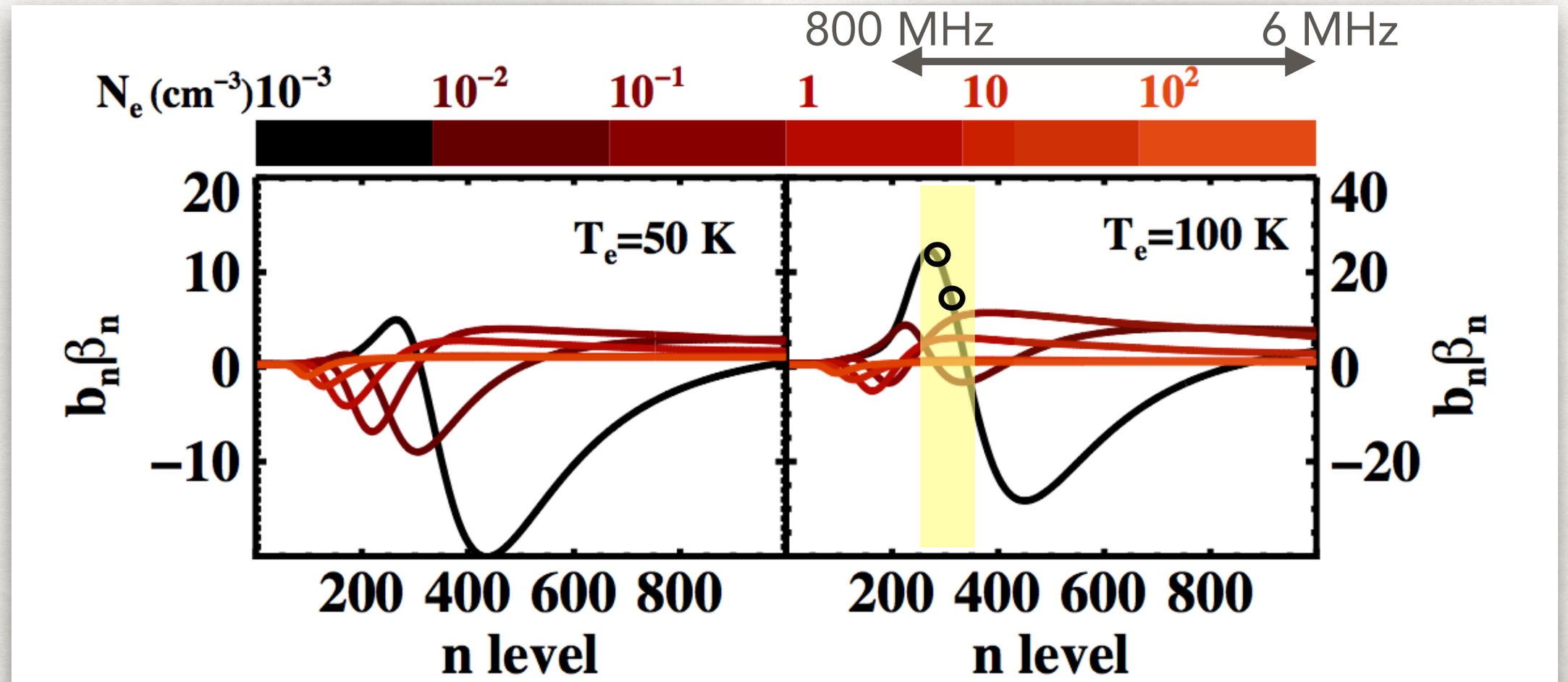

Salgado et al. 2017a,b

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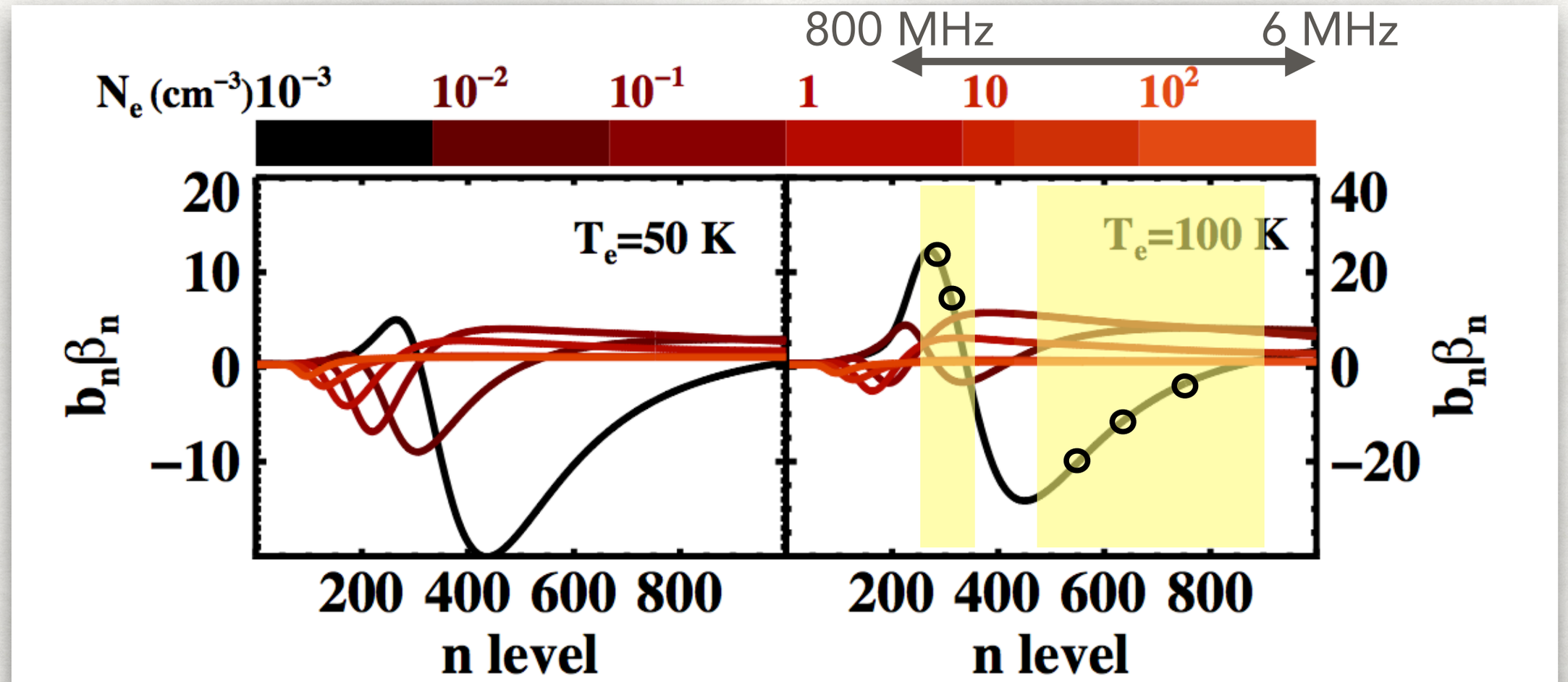


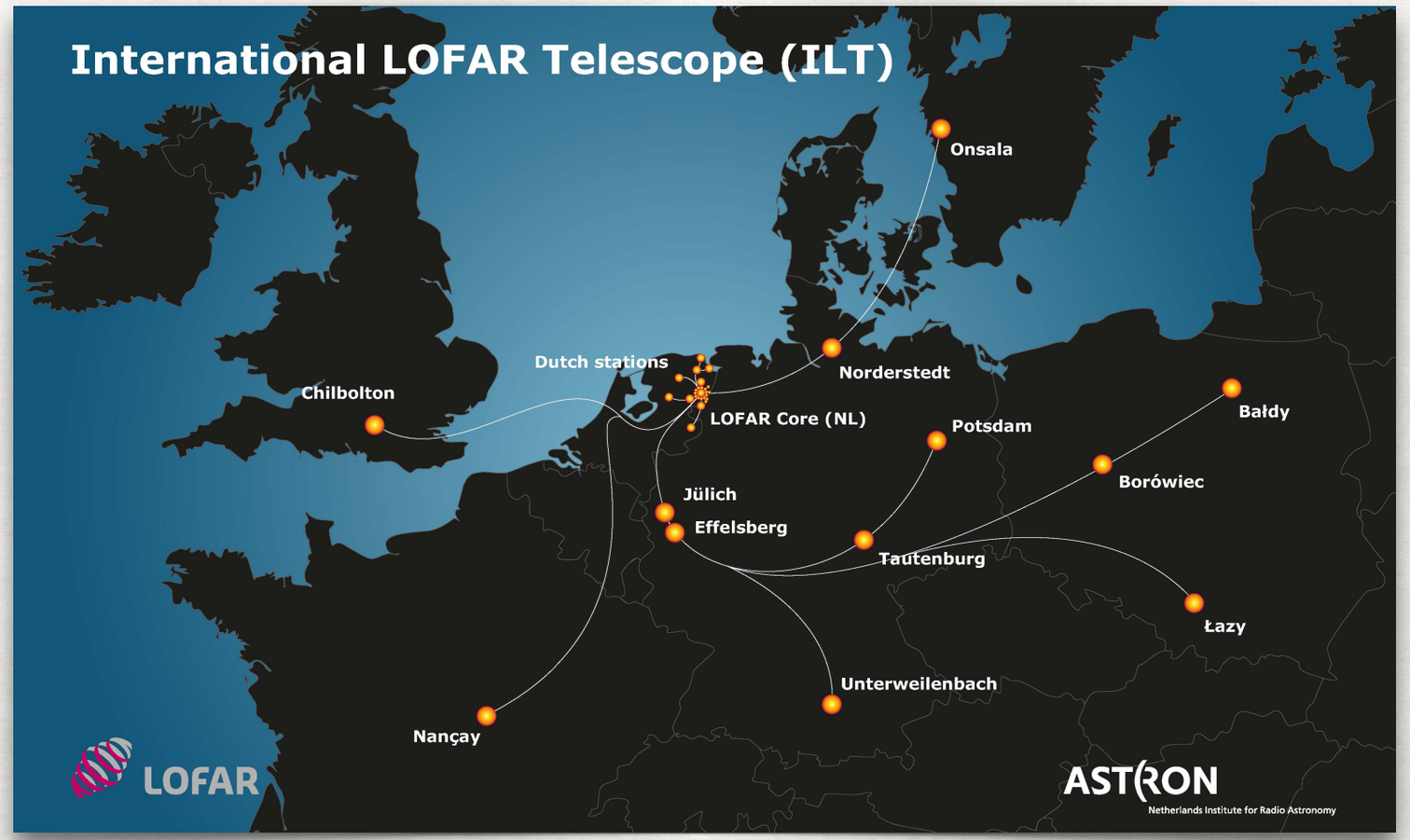
Salgado et al. 2017a,b

KEY INSIGHTS FROM CRRL

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

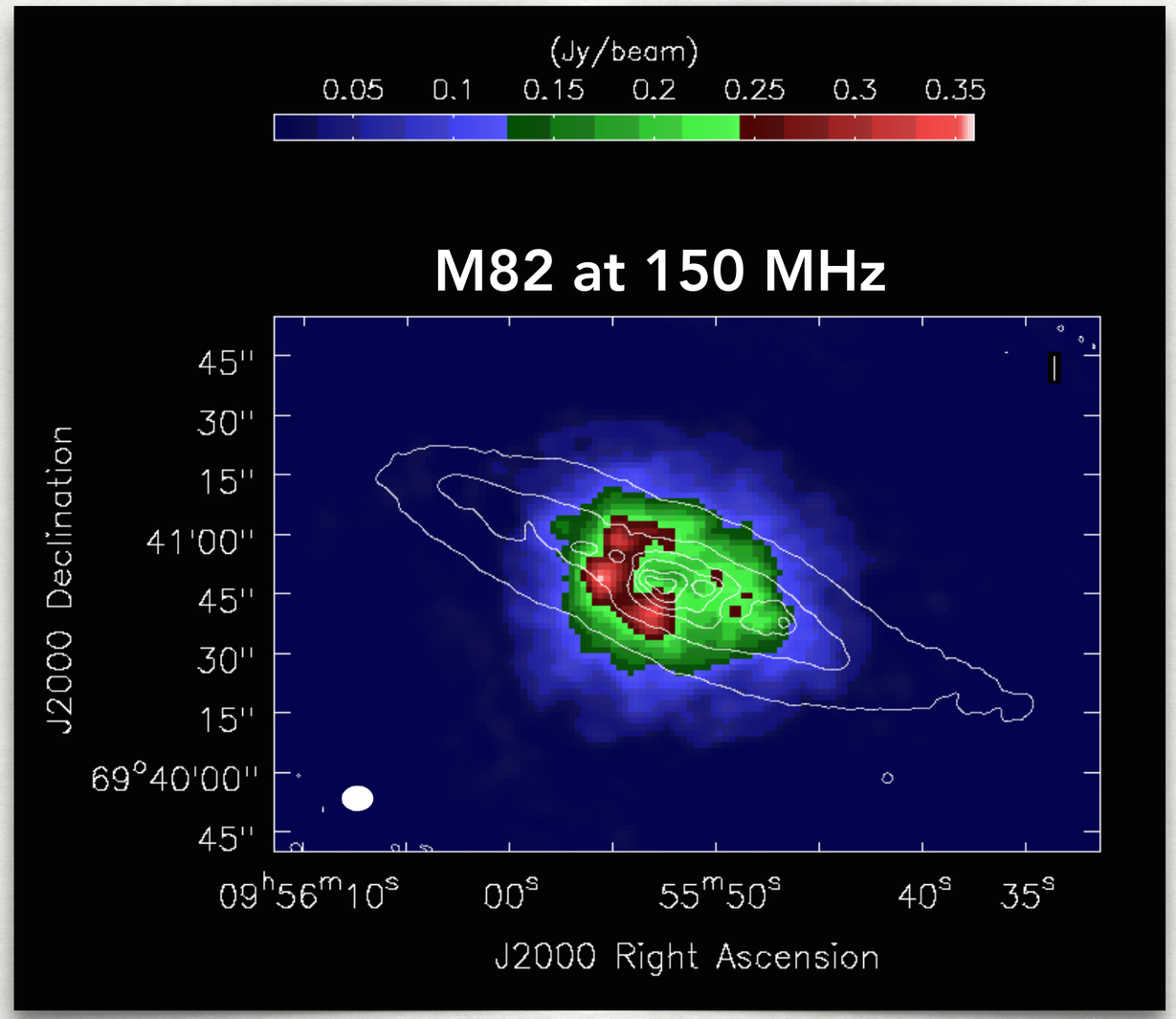
DETECTING EXTRAGALACTIC CRRL

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

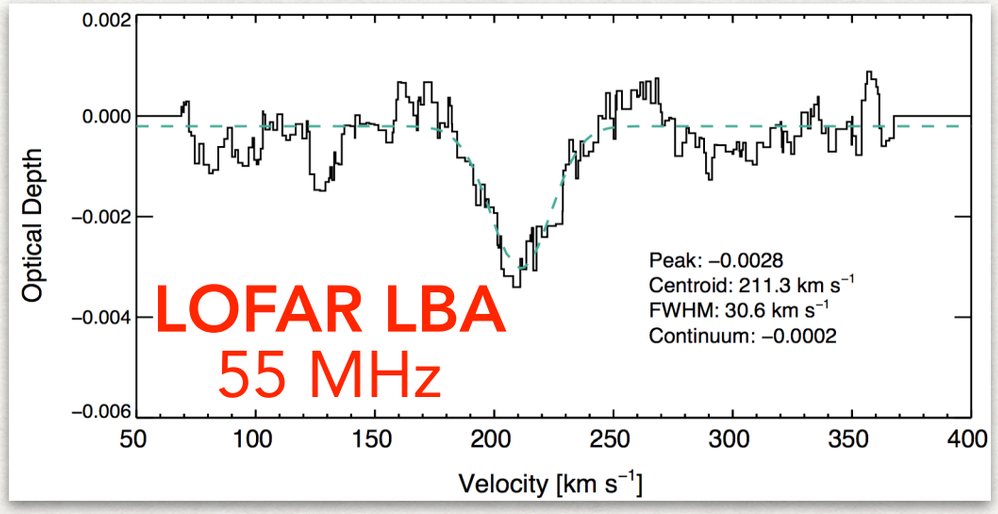


LOFAR DETECTIONS IN M82

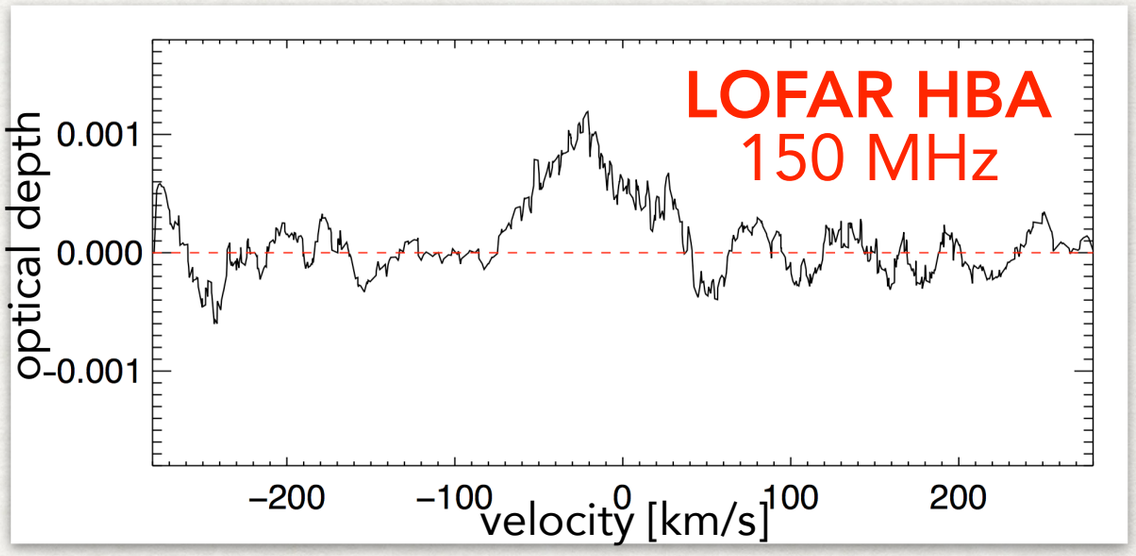
M 82
STARBURST
4 MPC AWAY
BRIGHT
WELL-STUDIED



courtesy MC. Toribio



L. Morabito et al. 2014

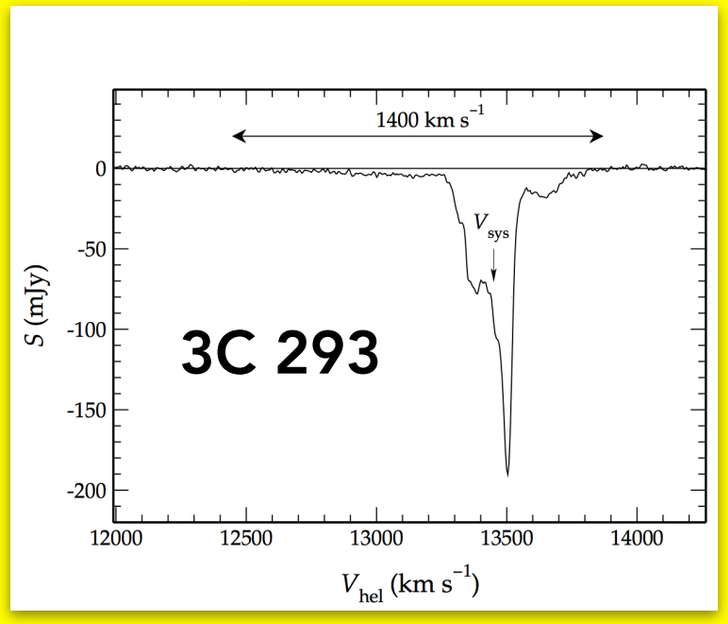


MC. Toribio et al. in prep.

CRRL AT COSMOLOGICAL DISTANCES

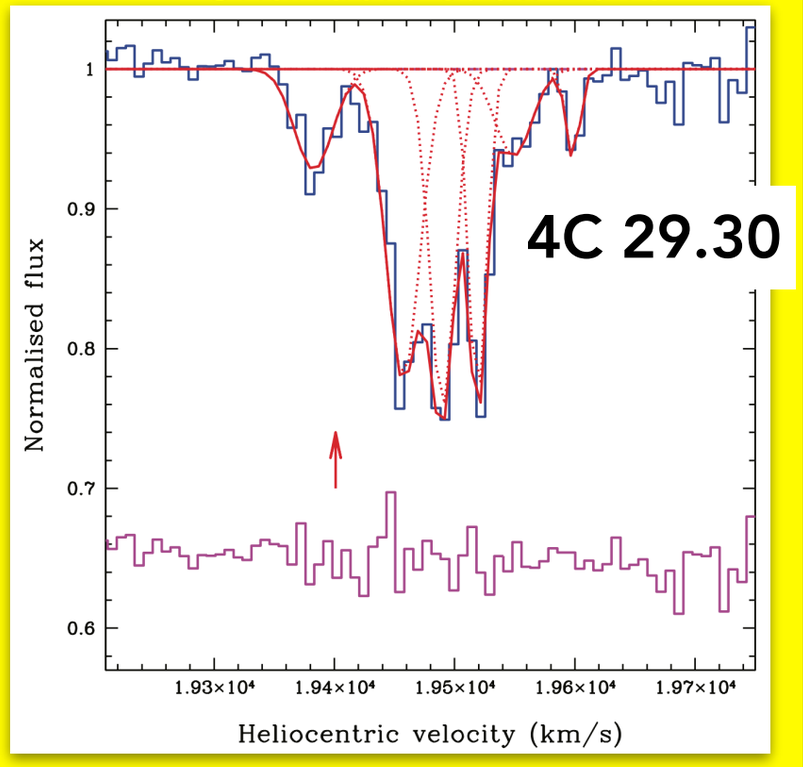
- bright (> few Jy in HBA)
- HI absorber
- compact
- steep spectrum

Morganti et al. 2003

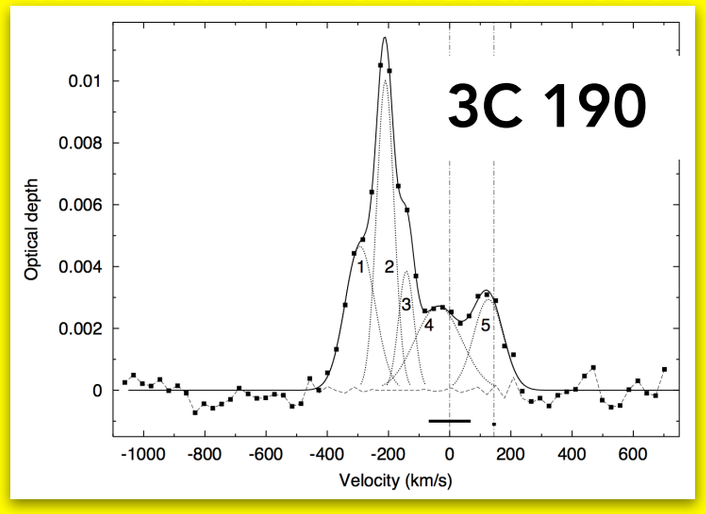


LOFAR HBA OBSERVATIONS
PI: M. BRIENZA

Chandola et al. 2010



Ishwara-Chandra et al. 2003



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

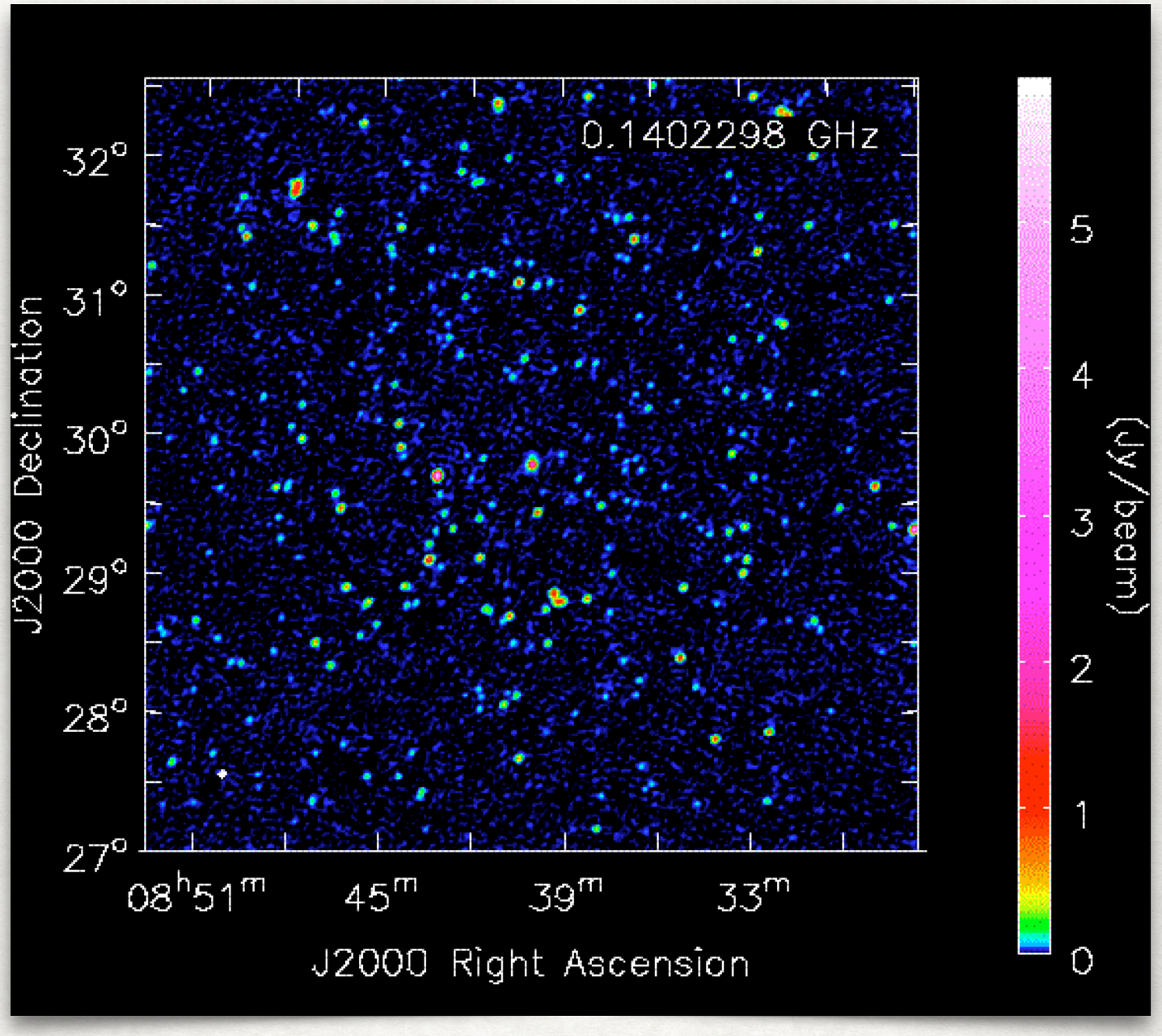
DATA PROCESSING

About pipeline

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

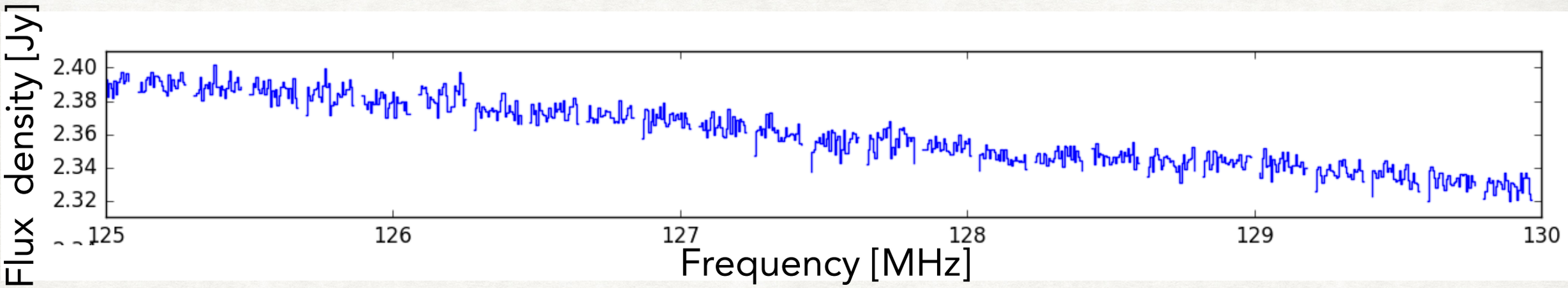
Essential for processing

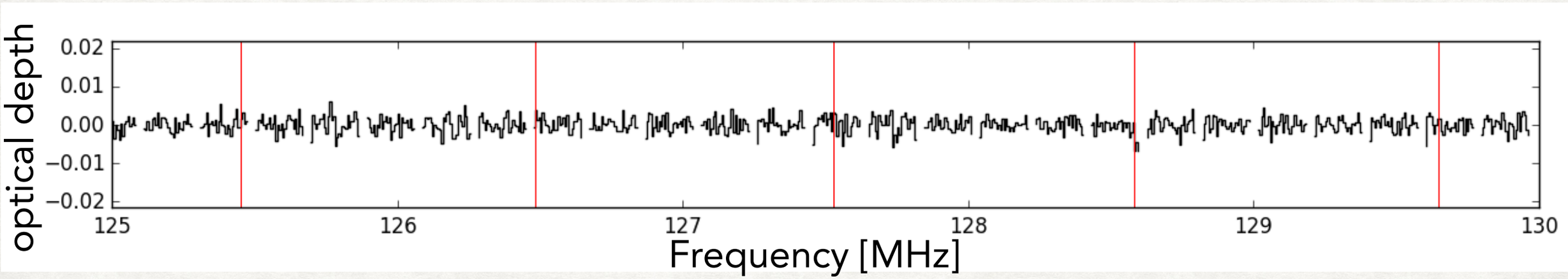
- SURFSara NL grid
  - ~few days processing
- DPPP, WSClean, LoSoTo



6 KHZ CHANNEL IMAGE
10 MJY/BEAM
3X THERMAL NOISE

SPECTRAL PROCESSING

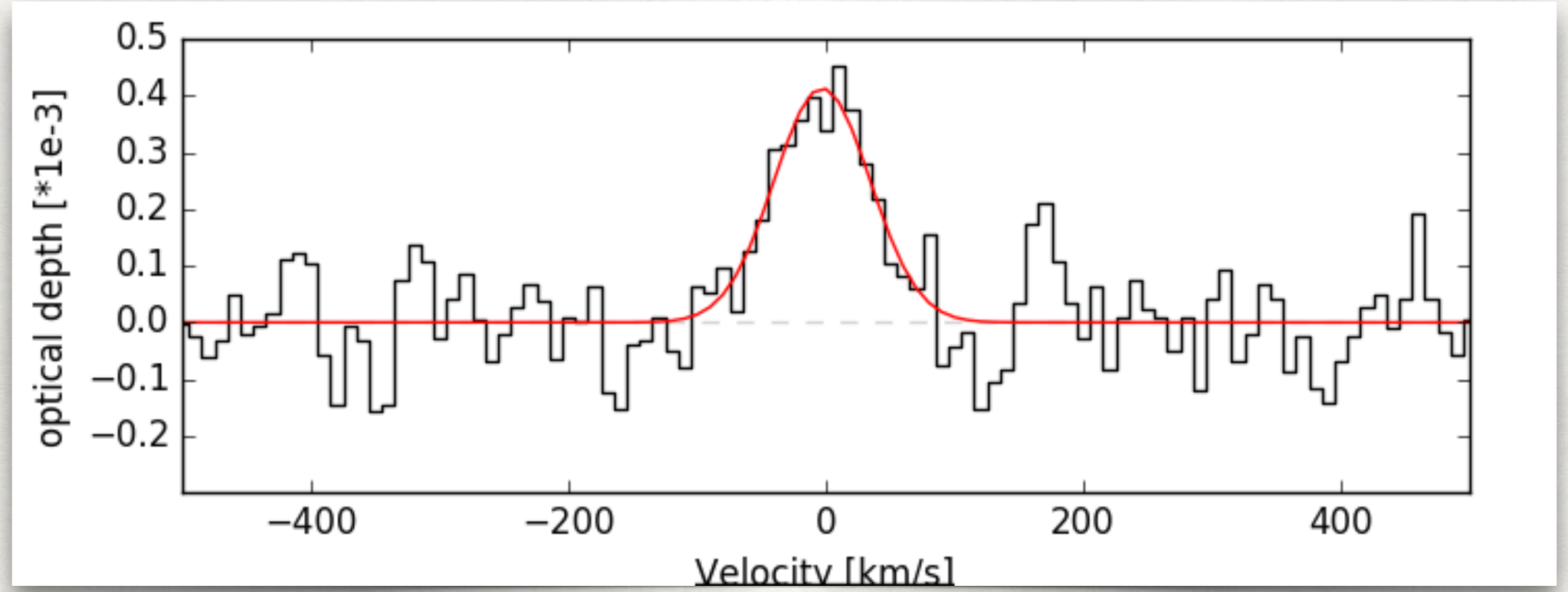




30–40 lines between 115-162 MHz

20–25 lines to stack (RFI and lines falling on channel edge)

3C 190 DETECTION



S(150 MHz) ~ 20 Jy

16 lines

stack center, z = 1.196

v_{FWHM} = 88 km/s

effective frequency = 133 MHz

effective quantum number, n = 287

3C 190

- z_{opt} = 1.195
- center galaxy of a group
- HI absorption from jet interaction
- in-falling foreground absorber

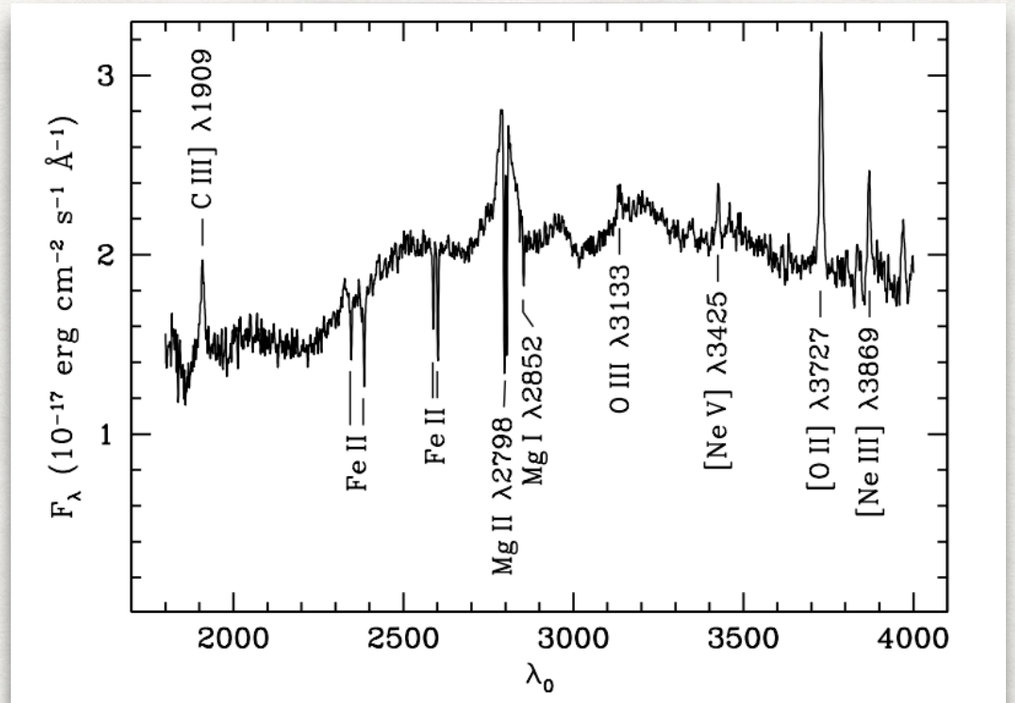
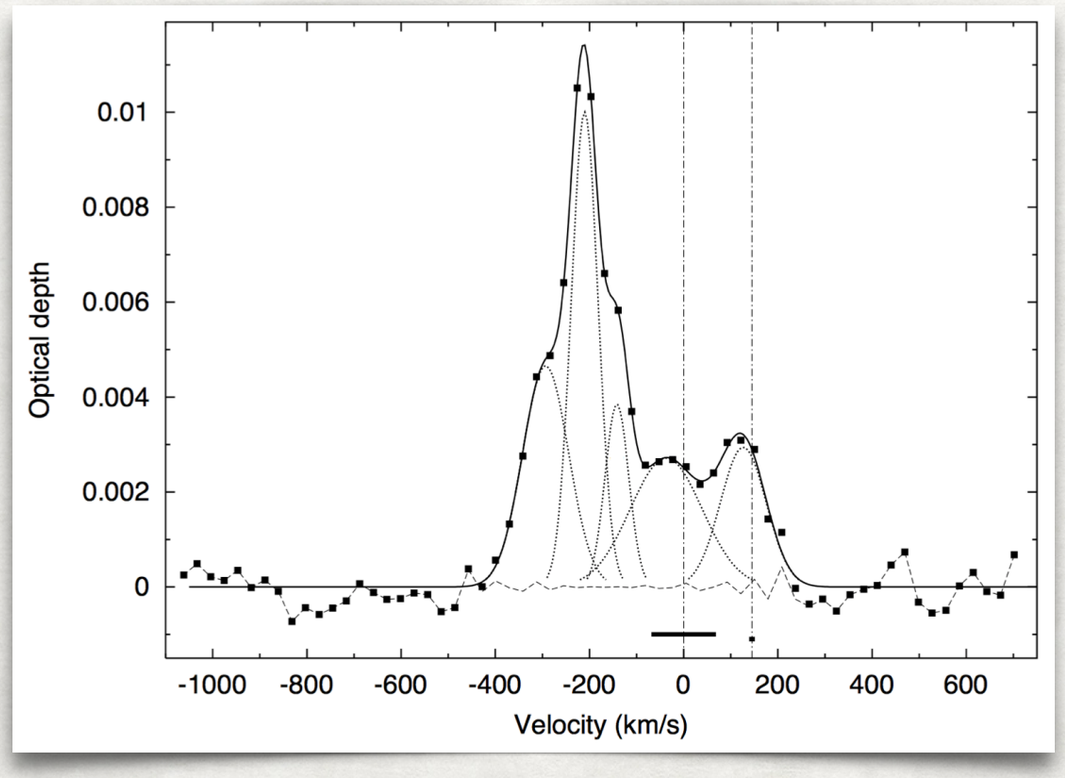


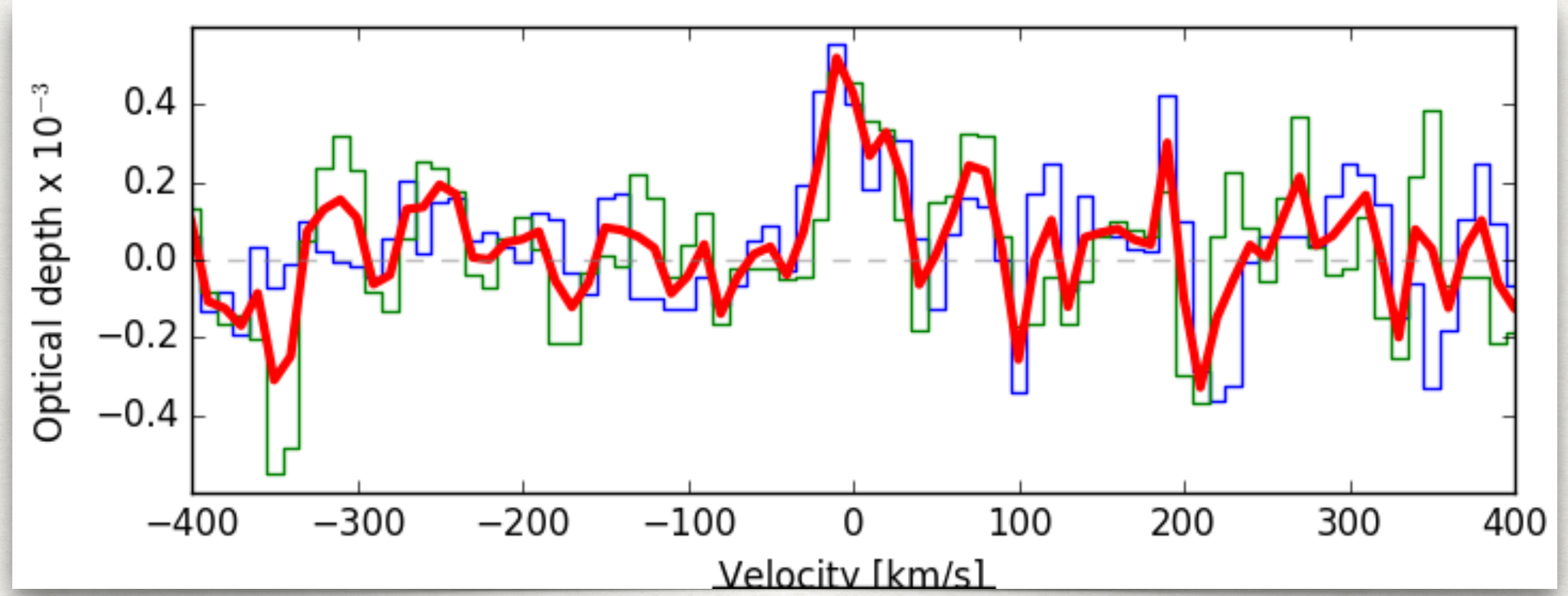
FIG. 4.—Spectrum of 3C 190 (the quasar itself). The absorption lines all appear to come from a single system close to the quasar redshift.

In-falling foreground absorber
at z = 1.196
Stockton & Ridgway 2001



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

3C 293 DETECTION

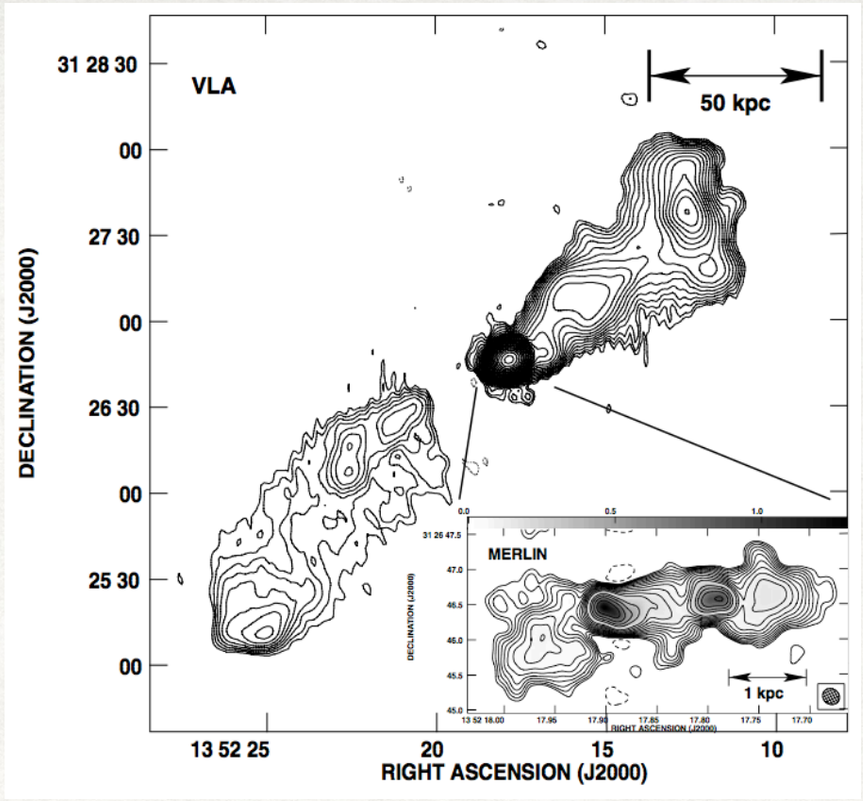


S(150 MHz) ~ 15 Jy
12 lines
stack center, z = 0.045
v_{FWHM} = 40 km/s
effective frequency = 127 MHz
effective quantum number, n = 371

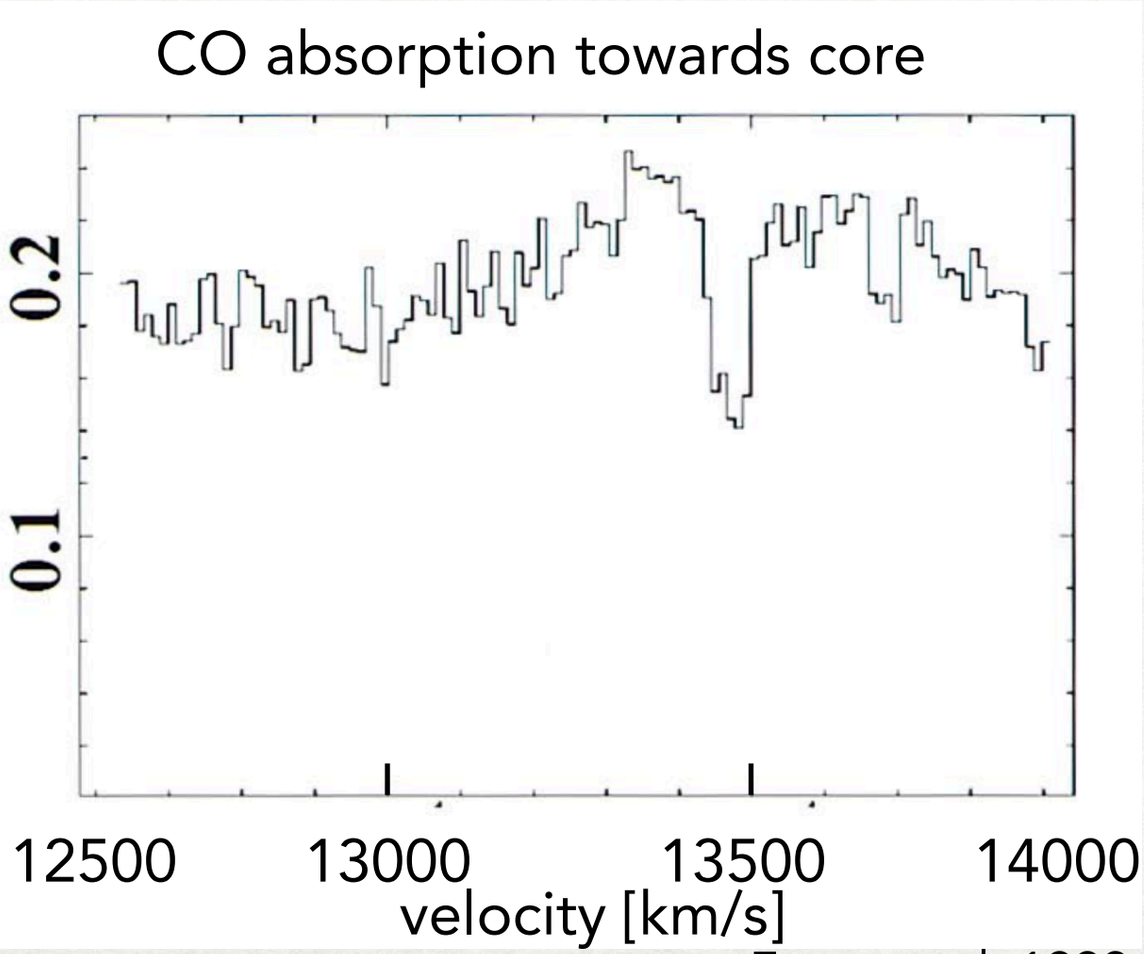
confirmed with
two observations
blue = 4 hr
green = 2.5 hr

3C 293

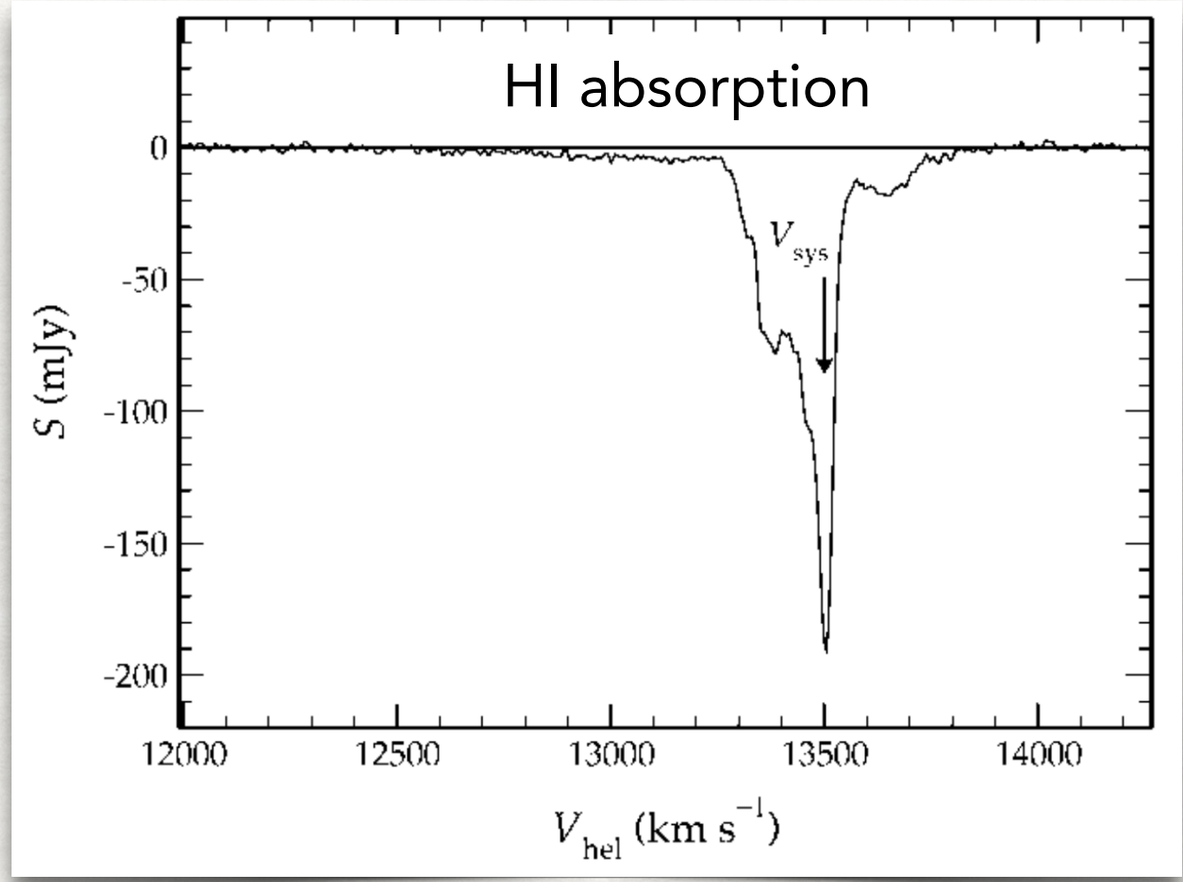
- z_{opt} = 0.045
- HI absorption, v_{FWHM} ~ 40 km/s
- CO absorption, v_{FWHM} ~ 40 km/s



Beswick et al. 2004



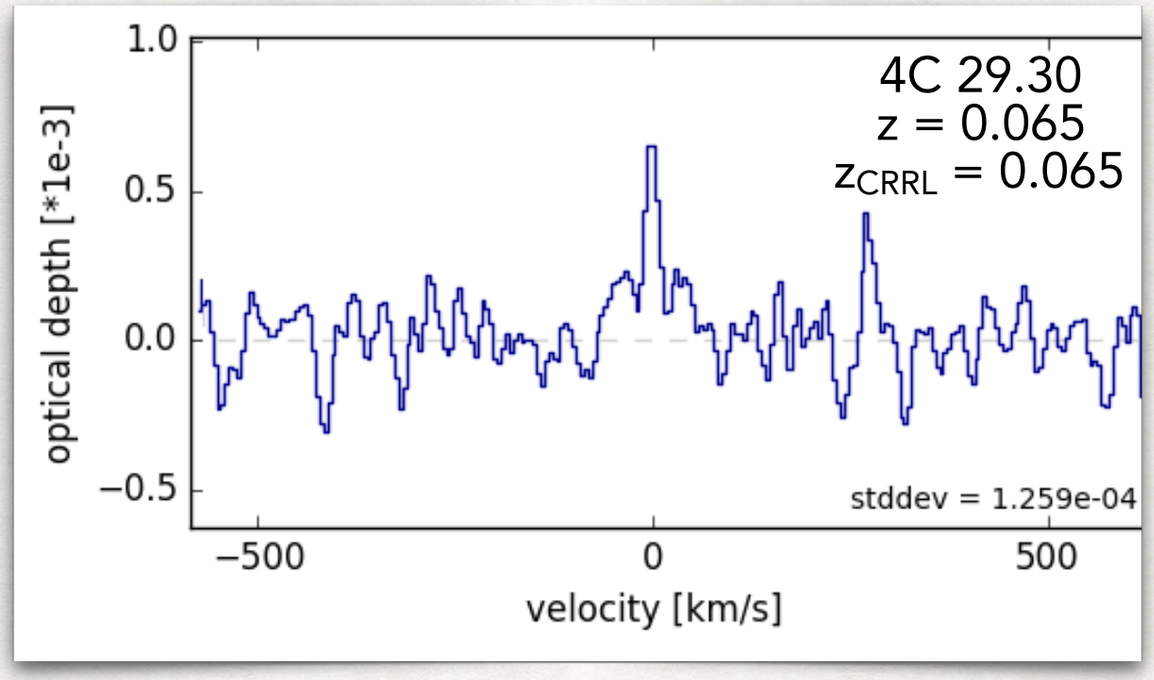
Evans et al. 1999

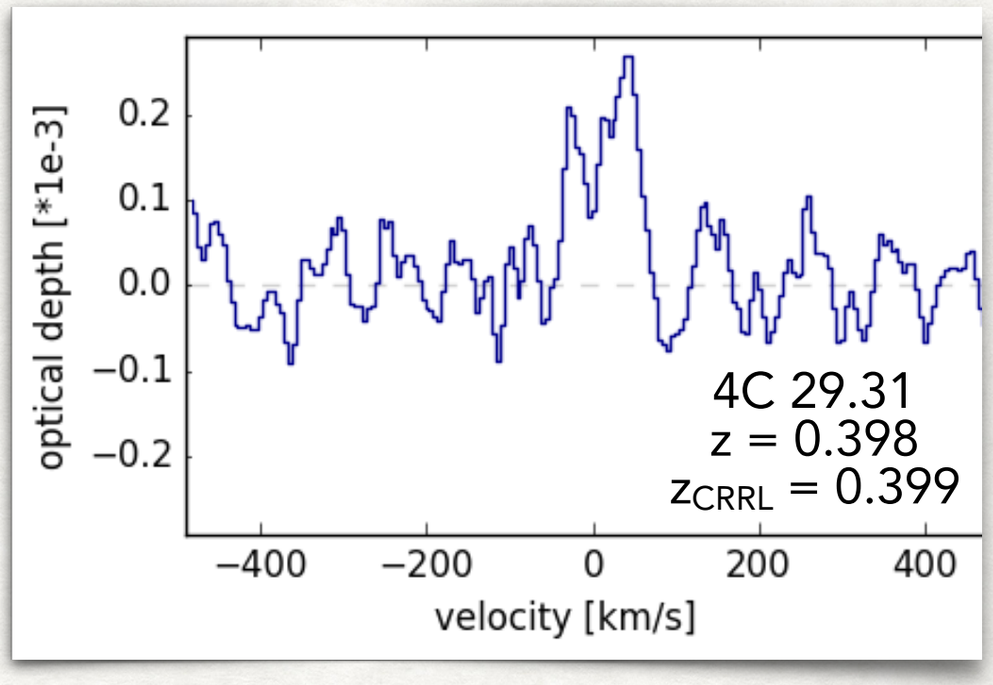


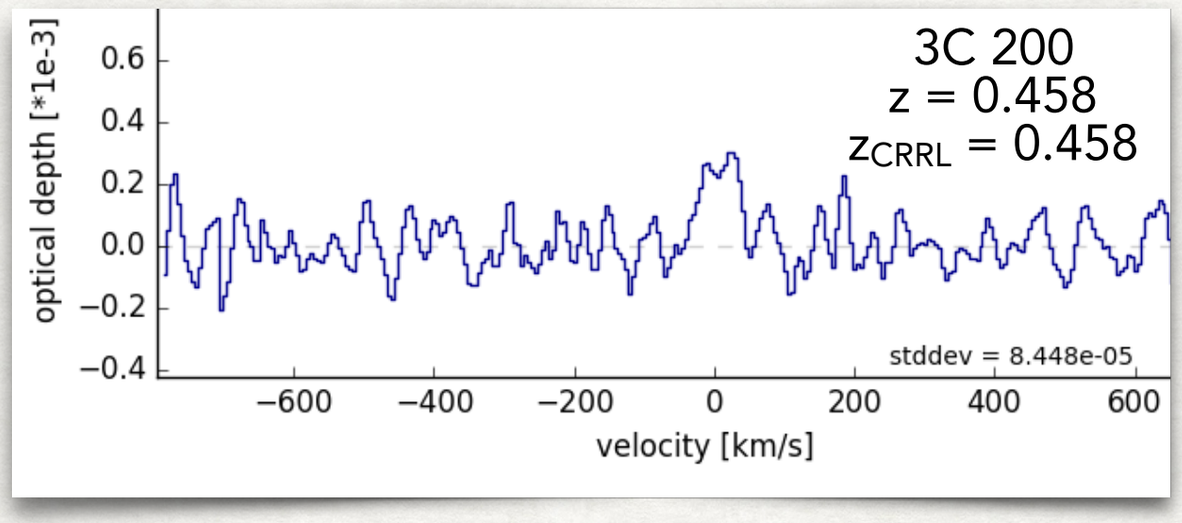
Morganti et al. 2003

4C 29.30 FIELD

PRELIMINARY !!

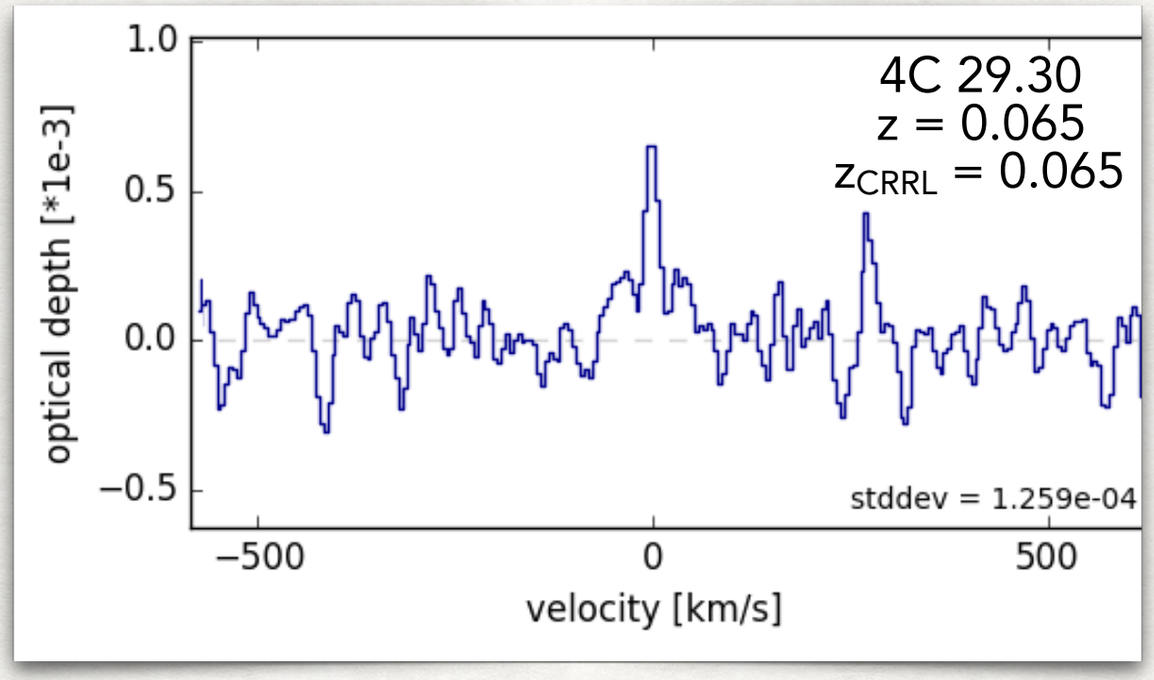


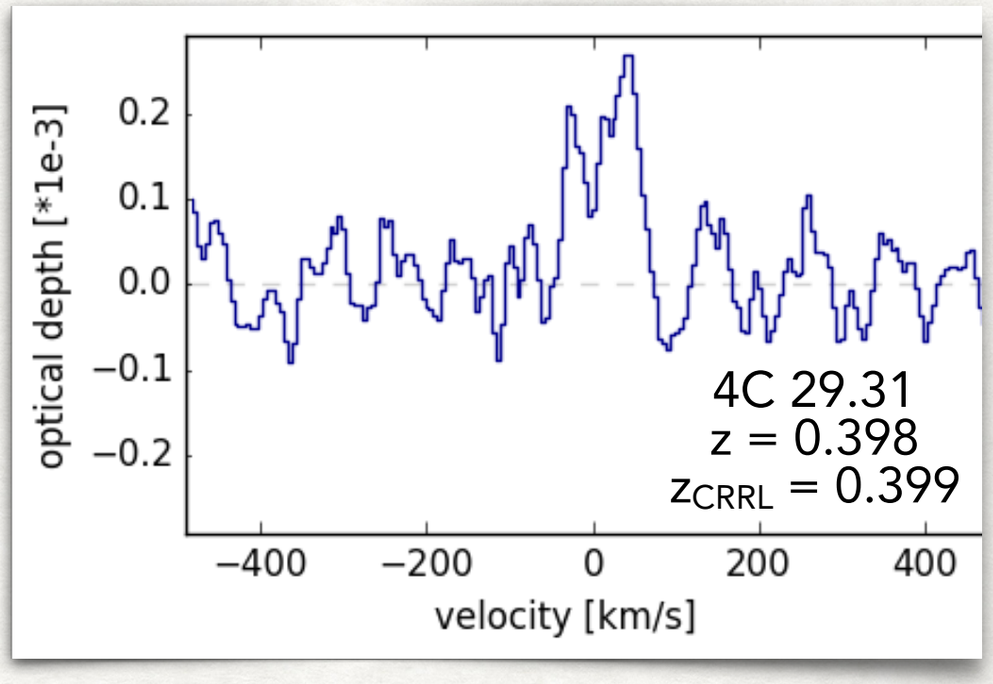


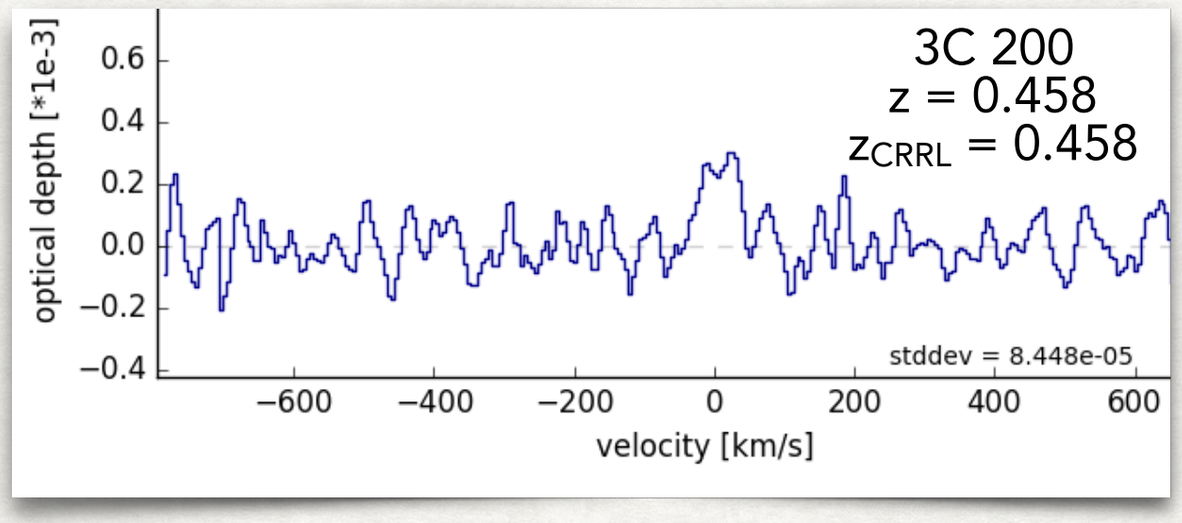


4C 29.30 FIELD

PRELIMINARY !!







Next steps for extra-gal CRRL → Follow up observations

→ LOFAR Tier 1 Survey

TAKE AWAY MESSAGES

- first CRRL detections out to high z + in AGN
  - 3C 190
  - 3C 293
  - 4C 29.30 + field

- CRRL can probe atomic gas out to high redshifts
- follow up observations will provide the physical conditions

Grazie e buon appetito!