Opening up the Extragalactic Universe to Recombination Lines at Low Radio Frequencies

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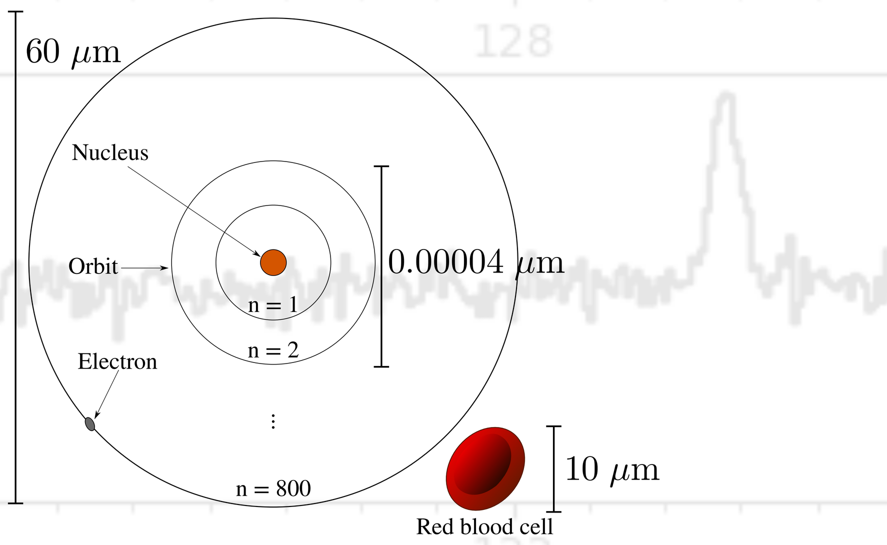
Abstract

Recombination lines involving high principal quantum numbers (n > 100) populate the radio spectrum in large numbers. Low frequency observations (<1 GHz) of radio recombination lines (RRLs) offer a new, if not unique, way to observe cold, largely atomic gas and warm ionized gas in other galaxies. Furthermore, they can be used to determine the physical state of emitting regions: temperature, density, pressure, size, and so forth. These properties make RRLs, potentially, a powerful tool of extragalactic ISM physics. Its conceivable to detect low-frequency RRLs out to cosmological distances illuminated by a strong radio continuum. Thanks to low-frequency telescopes like the Low Frequency Array (LOFAR), this is being explored for the first time.

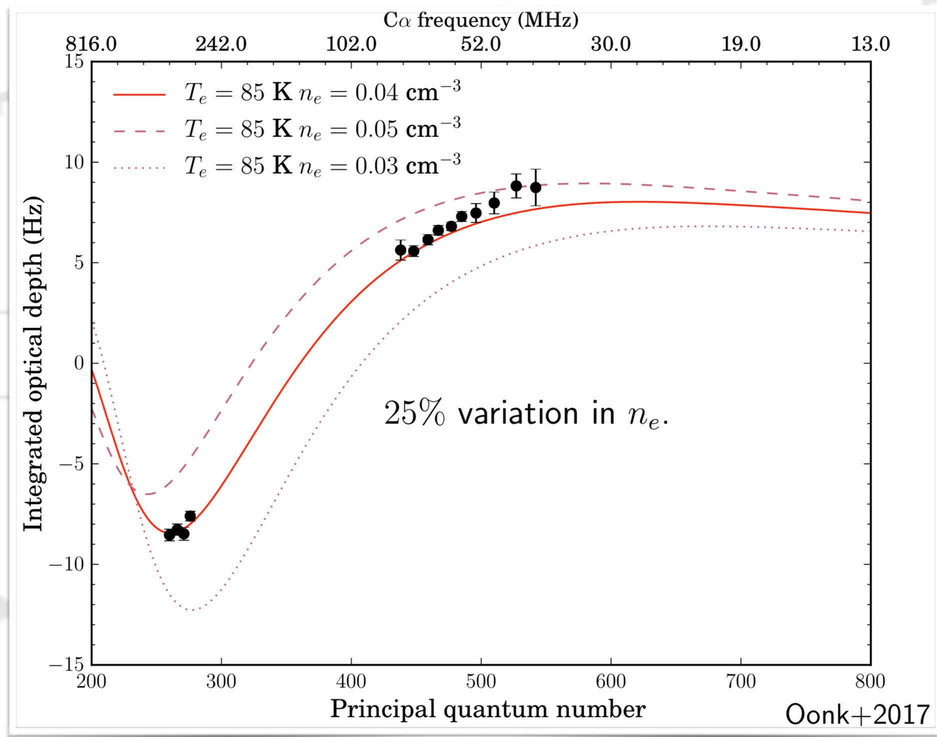
In this poster, we show that we have detected radio recombination lines at z = 1.124, centered at 133 MHz in the spectrum of the radio quasar 3C 190, making it the first time RRLs have been found outside of the local universe. Furthermore, since the spacing between each RRL is unique, we demonstrate how they can be used to determined radio source redshifts.

Low-frequency radio recombination lines



- tracers of diffuse gas in the ISM
  - (ionized) carbon, largely atomic gas (T_e ~ 100 K, n_e ~ 0.05 cm^{-3})
  - (ionized) hydrogen, warm and low-density (T_e ~ 8000 K, n_e ~ 0.5 cm^{-3})

Fig. 1: Carbon RRLs in our Galaxy, in front of Cassiopeia A, demonstrating how well RRLs can determine physical conditions (temperature and density) of the emitting gas.



3C190: first AGN targeted

- 3C190 (Fig. 2), ~compact, steep spectrum; 20 Jy at 150 MHz
- RRL detection (Fig. 3) at -9965km/s (80 Mpc)
- Modeling (Fig. 4) shows spectral line to be consistent with
  - intervening, dwarf-like galaxy (10^9 M_{sun})
  - high-velocity outflow material

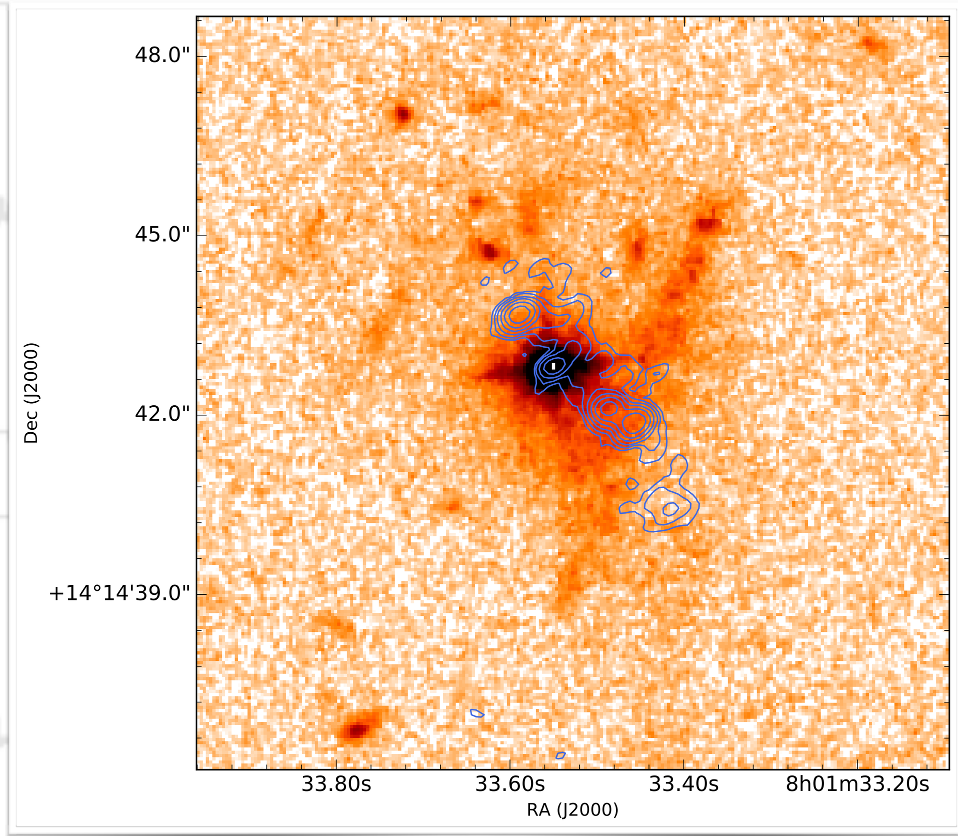


Fig. 2: The rich environment oft the quasar 3C190 (z=1.1946; 1''=8.5kpc) shown in an HST WFPC2 F702W image (Stockton & Ridway 2001). Superimposed are MERLIN 1658 MHz radio contours at σlog$_5$([1, 1.5, 2, 2.5, 3, 3.5]) mJy/beam, showing the 22 kpc extent of lobe hot spots.

Fig. 3: Detection of a radio recombination line due to stimulated emission at quantum level, n= 285, with a velocity centered on z = 1.12405 (z = 1.12355) originating from hydrogen (carbon). This is the average profile of a single line, at 133 MHz, as a result of stacking 13 recombination lines in the spectrum of 3C190.

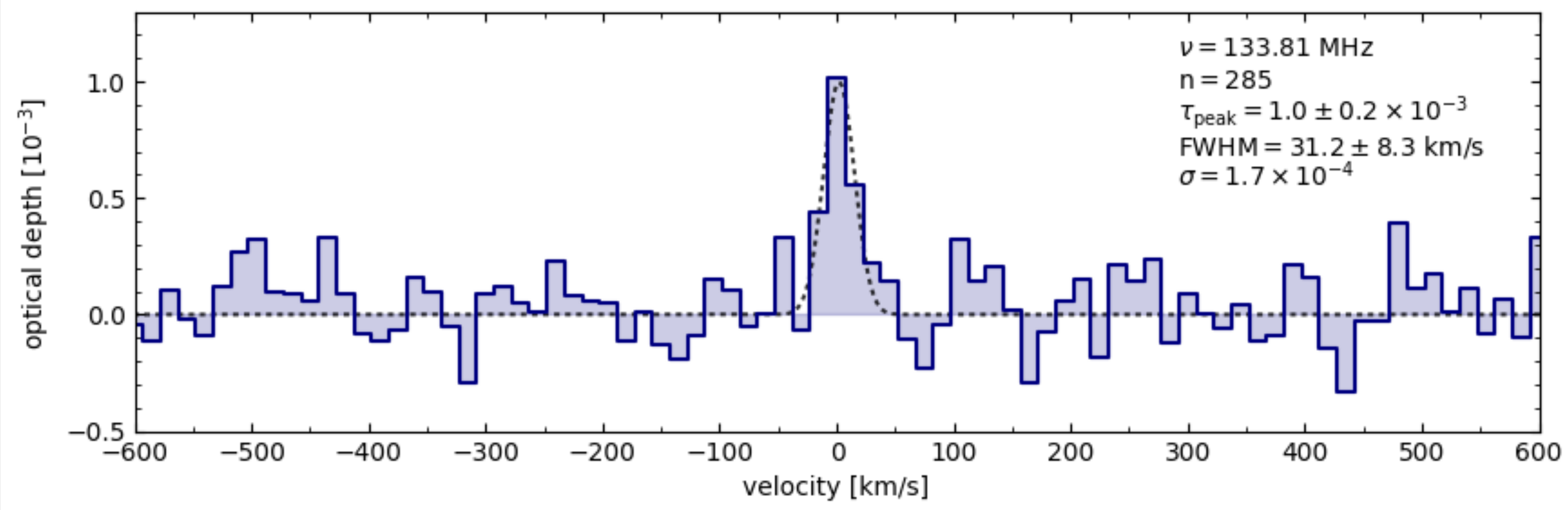
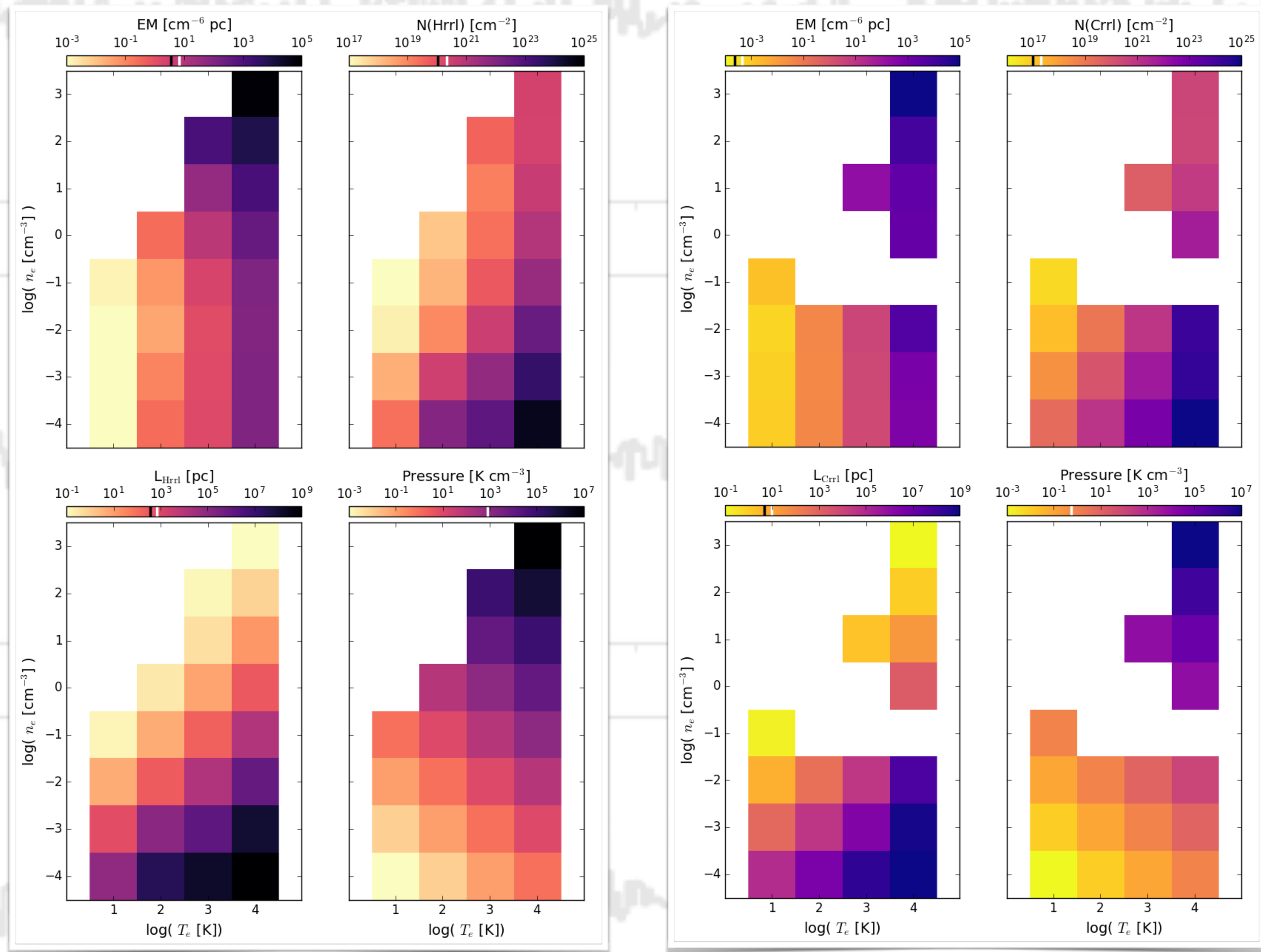


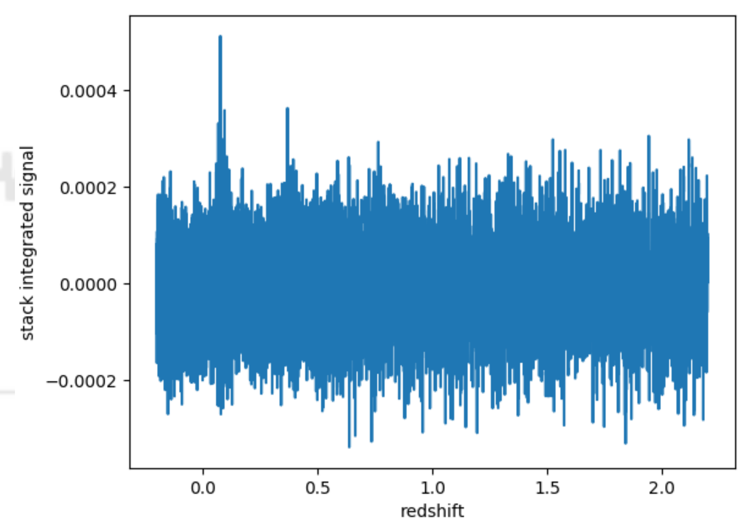
Fig. 4:Derived physical properties from modeling of hydrogen (left) and carbon (right) RRL departure coefficients. For input physical conditions, electron density and temperature, the axes shown, we computed a non-LTE departure coefficient via RRL modeling (Salgado et al. 2017a,b), assuming . We then derive the emission measure (top left) and corresponding column density (top right) and path-length (bottom left) of the RRL emission. Additionally we show the electron pressure (bottom right). Values representing a face-on (black) and an edge-on (white) Milky Way are shown with dashes in the color bars.

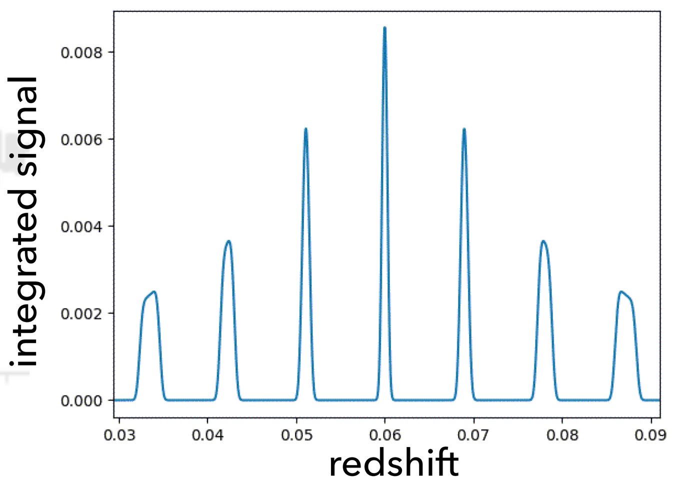


Emig et al. in prep, a

Determining redshift using stacked RRLs

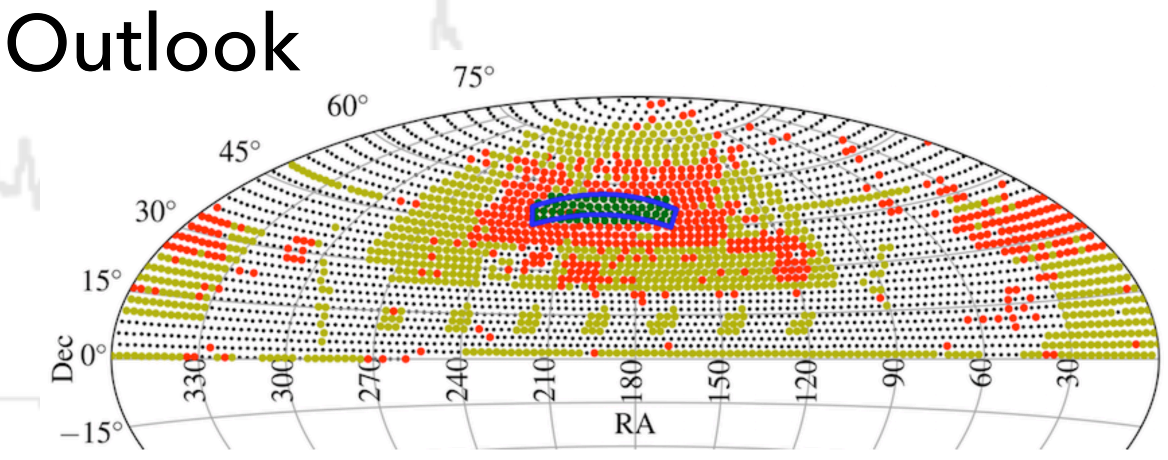
- for a given species, spacing between each recombination line is unique
- obstacles:
  - need to stack RRLs to detect since they are extremely faint (τ = 10^{-3} – 10^{-4})
  - bandpass and continuum estimation in LOFAR observations is very poor
  - significant signal at a given redshift is buried in the noise (for integrated signal vs. z)
- solution: determine z (and significant signal) with expected signal ringing vs. z





Emig et al. in prep, b

Future Outlook



Shimwell et al. in prep

- 3C190 was the first AGN searched! hopefully many more detections to come
- determine origin of gas in spectrum of 3C190: lower and higher frequency observations of RRLs
- understand where RRLs can be found: target well-known objects
- population studies: survey of northern sky at 150 MHz, LOFAR Two Meter Sky Survey (Shimwell+ 2017)