CRRLs with LOFAR: An Update

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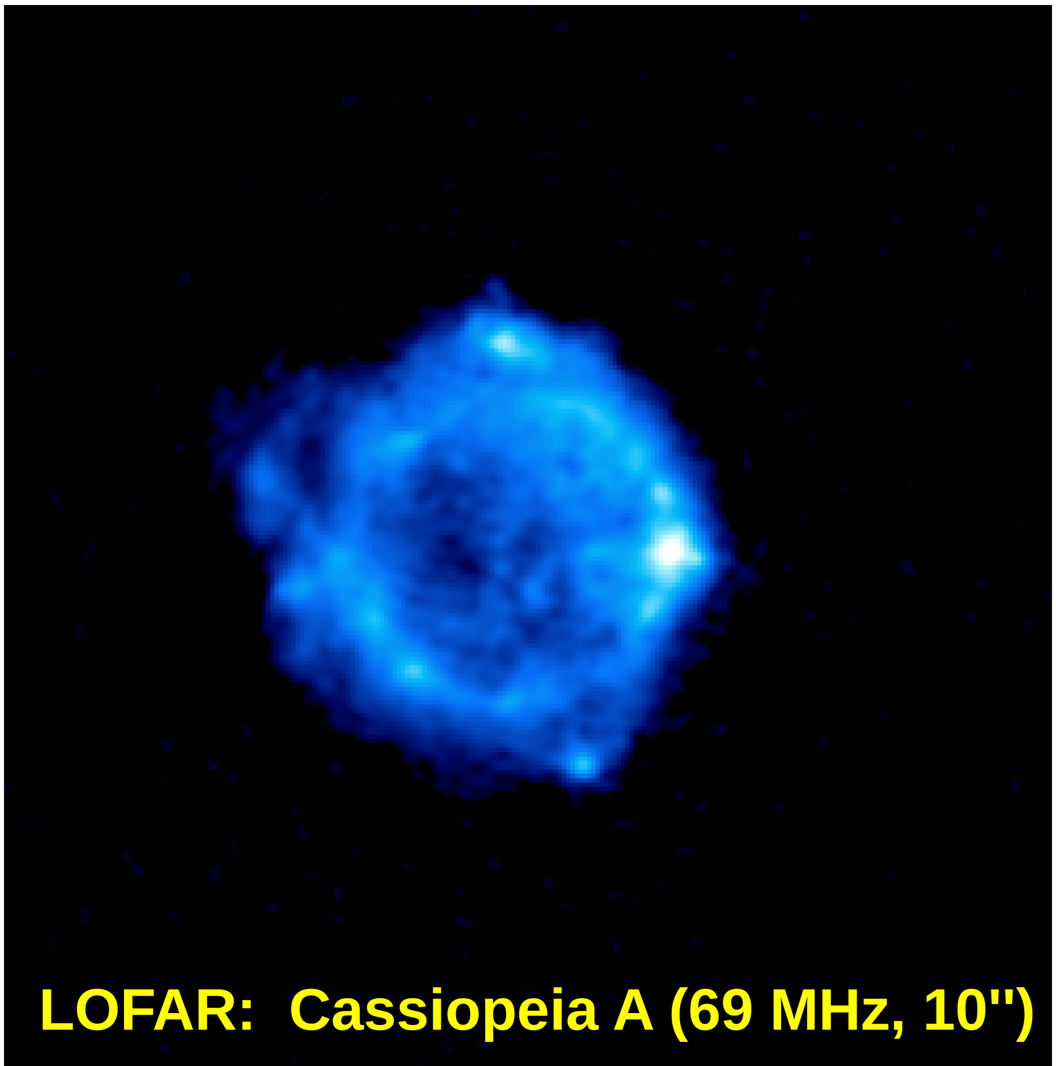
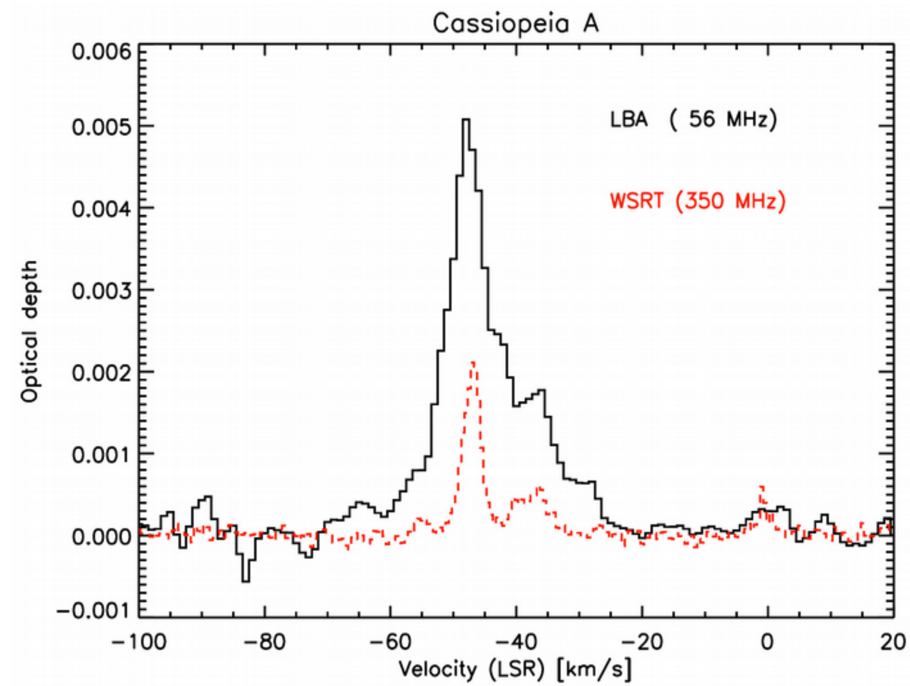
++ LOFAR Galactic KSP group



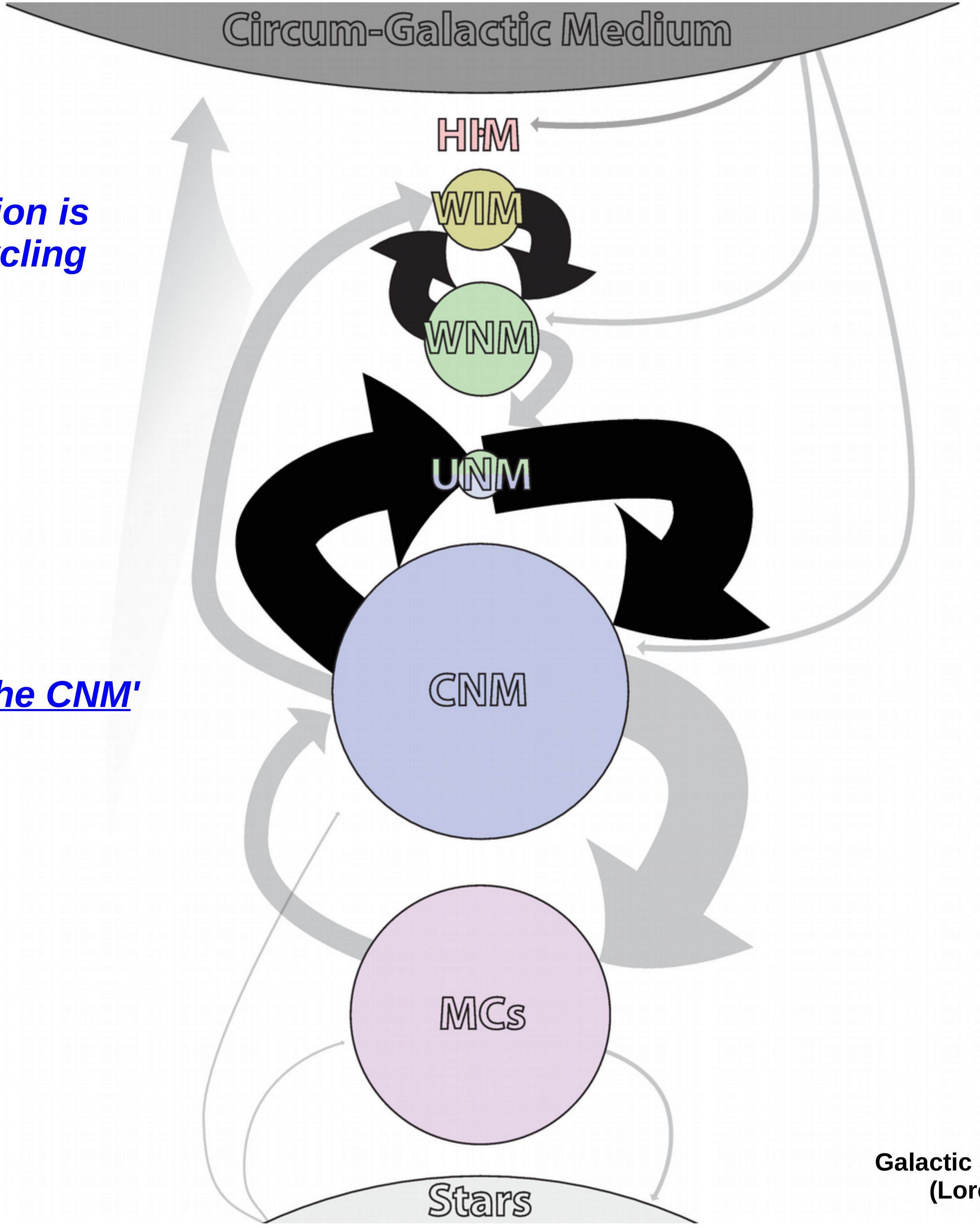


Cas A: 3 cold clouds along l.o.s

1) ***-47 km/s (Perseus Arm)***
2) **-38 km/s (Perseus Arm)**
3) **0 km/s (Orion Arm)**

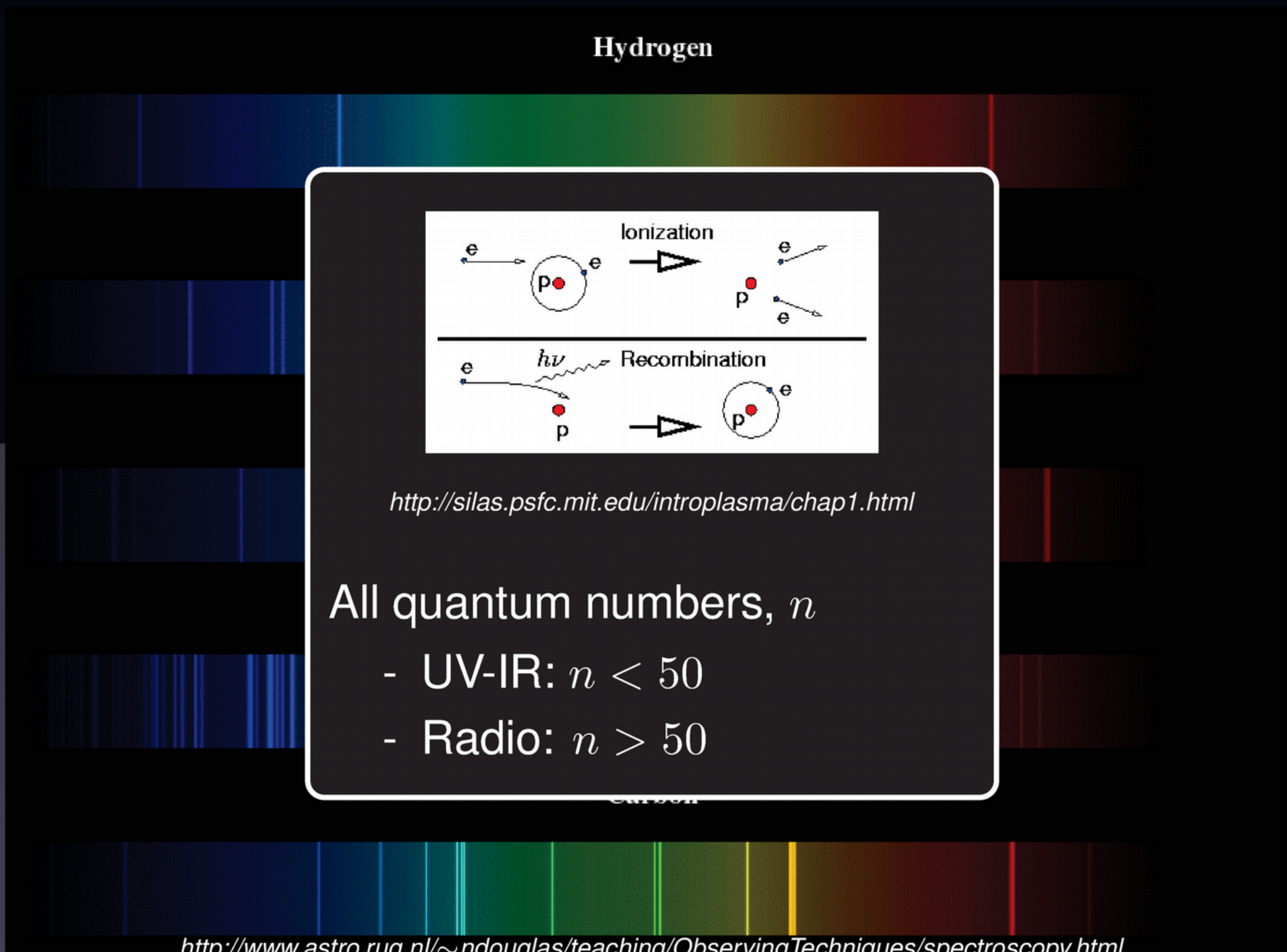
'Galaxy Evolution is driven by recycling of the ISM'

'[CRRLs trace the CNM](#)'



Galactic Science with the SKA (Lorentz center 2014)

Recombination Lines



http://silas.psfc.mit.edu/introplasma/chap1.html

All quantum numbers, n

- UV-IR: $n < 50$
- Radio: $n > 50$

http://www.astro.rug.nl/~ndouglas/teaching/ObservingTechniques/spectroscopy.html

Building the Non-LTE Model

Salgado et al. (subm.)

1. Set $\mathrm{T_e}$ and $\mathrm{n_e}$
2. Populate levels up to $\mathrm{n} = 2000$ assuming LTE

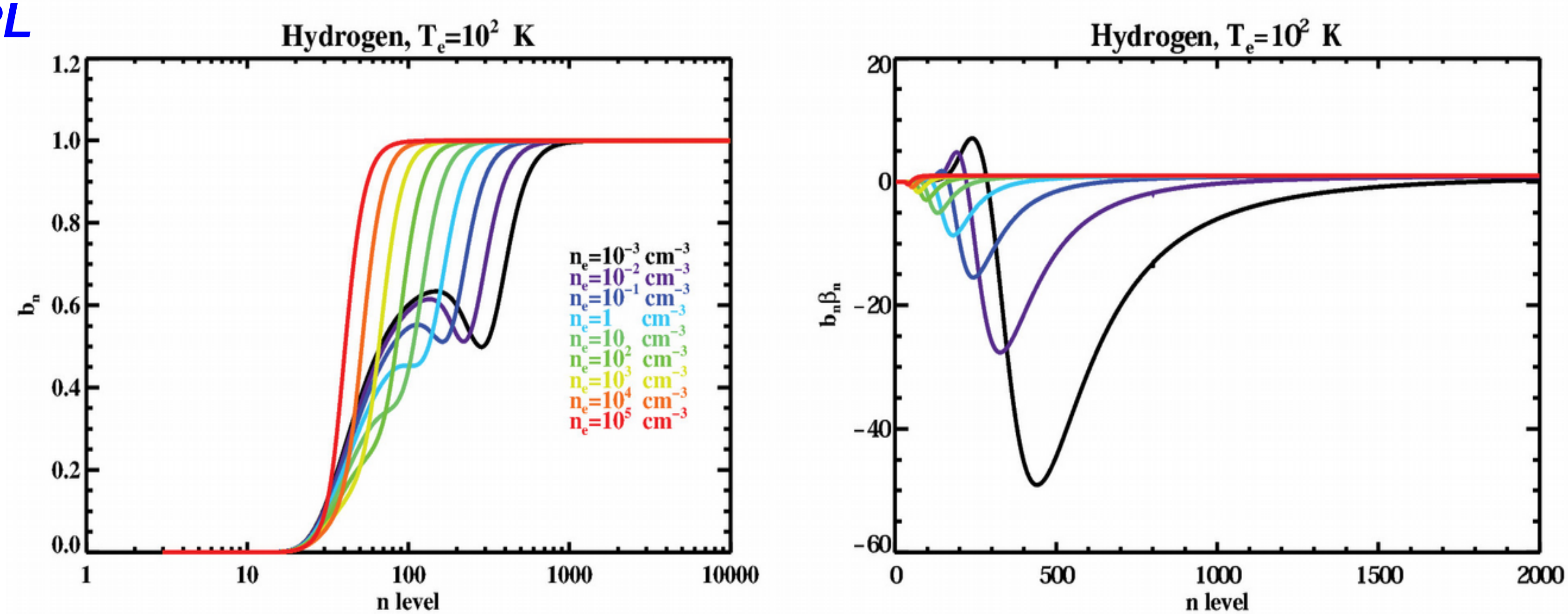
$$N_n^* = n_e N_{ion} \left(\frac{h^2}{2\pi m_e k T_e} \right)^{3/2} \frac{w_n}{2} e^{\chi_n}$$

3. Define ambient radiation field $(S_\nu \propto \nu^{-\alpha})$
4. Populate / depopulate levels
   - Collisional: level transitions, recombination, ionization
   - Radiative: recombination (+ cascade downwards)
   - Spontaneous: emission
   - Induced: emission, absorption
   - Dielectronic-like recombination
5. Calculate departure coefficients $N_n = b_n N_n^*$
6. Calculate optical depth $\int \tau_\nu \mathrm{d}\nu \propto \frac{\mathrm{d}\ \mathrm{ln} b_n}{\mathrm{d}n}$ ~ $(b_n \beta_n)$

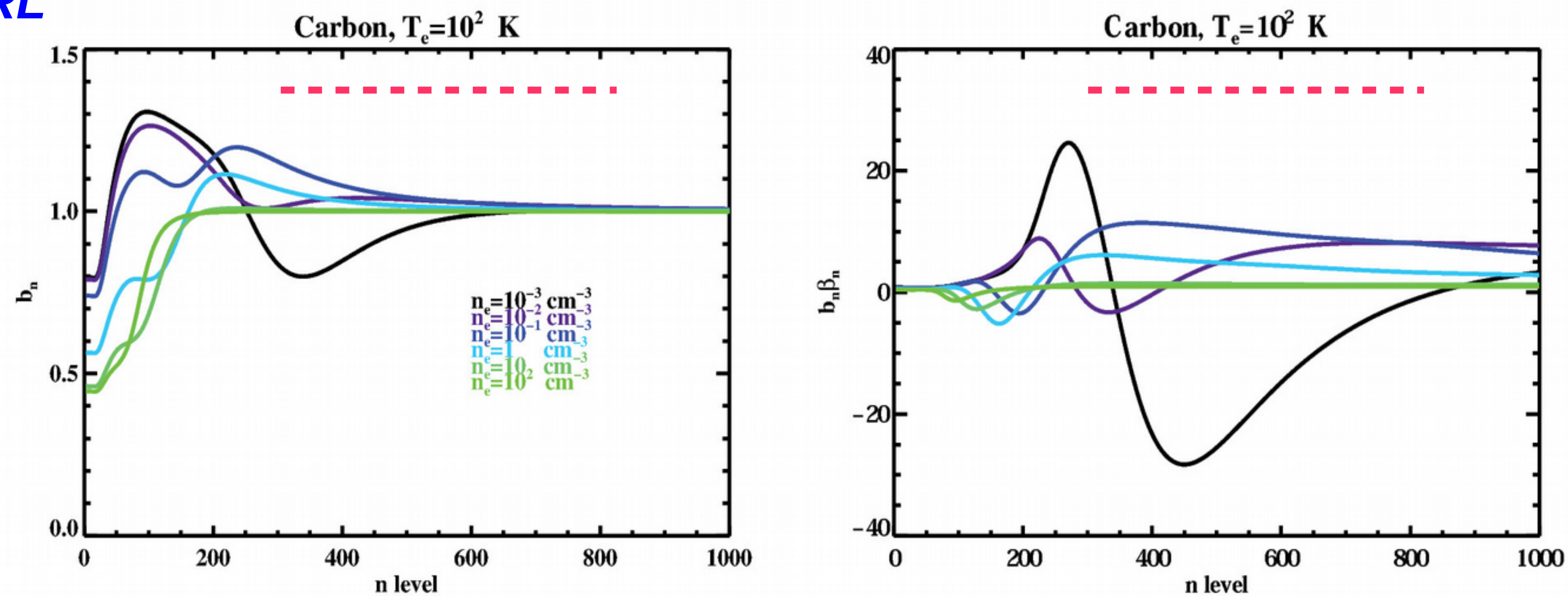
<u>RRL models</u>: new full (n,l) treatment

[Salgado et al. (subm.)]

HRRL



CRRL



RRL models: Line width broadening

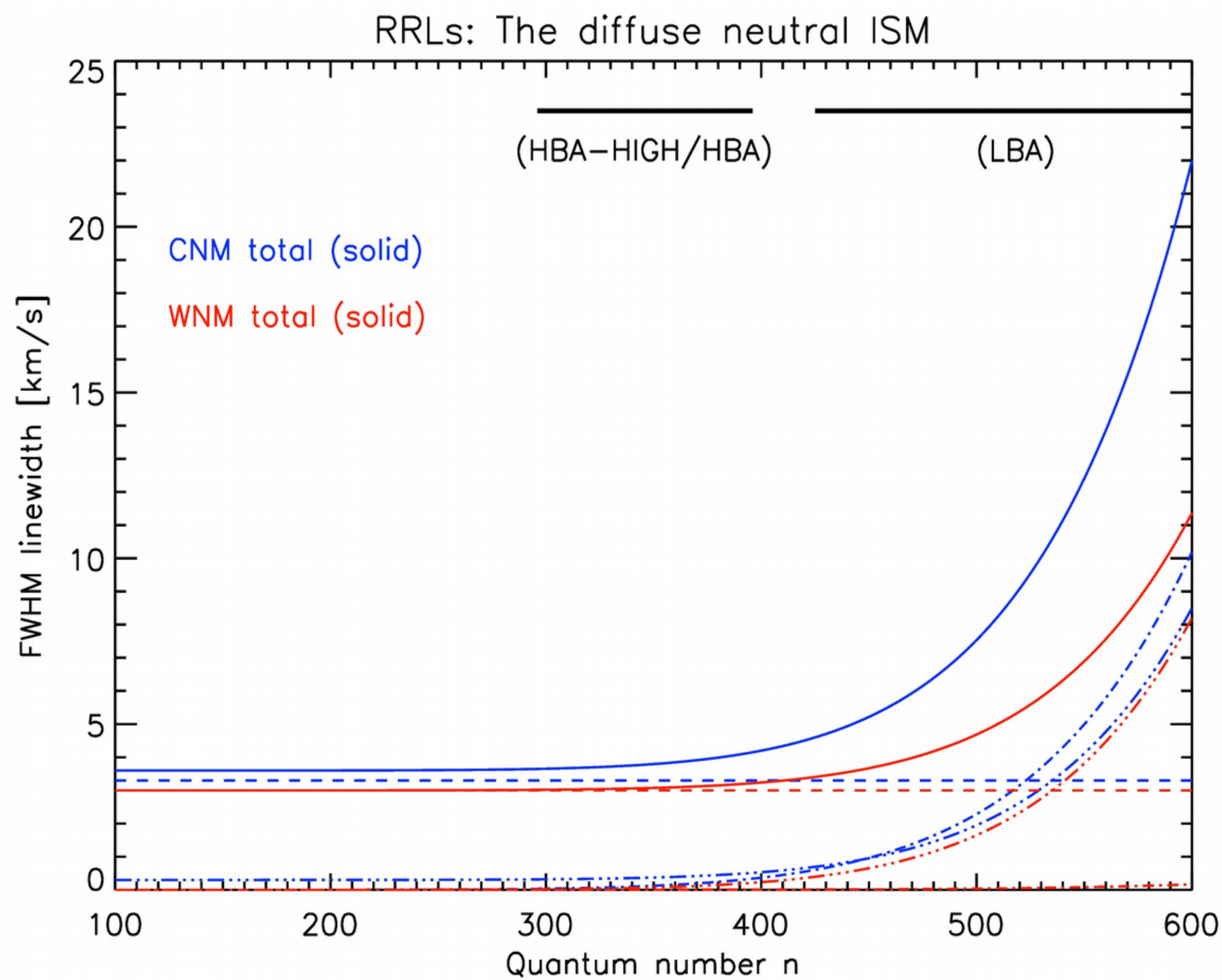
Total (solid) width

Contributions:

(1) Doppler (dash)

(2) Pressure (dash-dot)

(3) Radiation (dash-dot-dot)

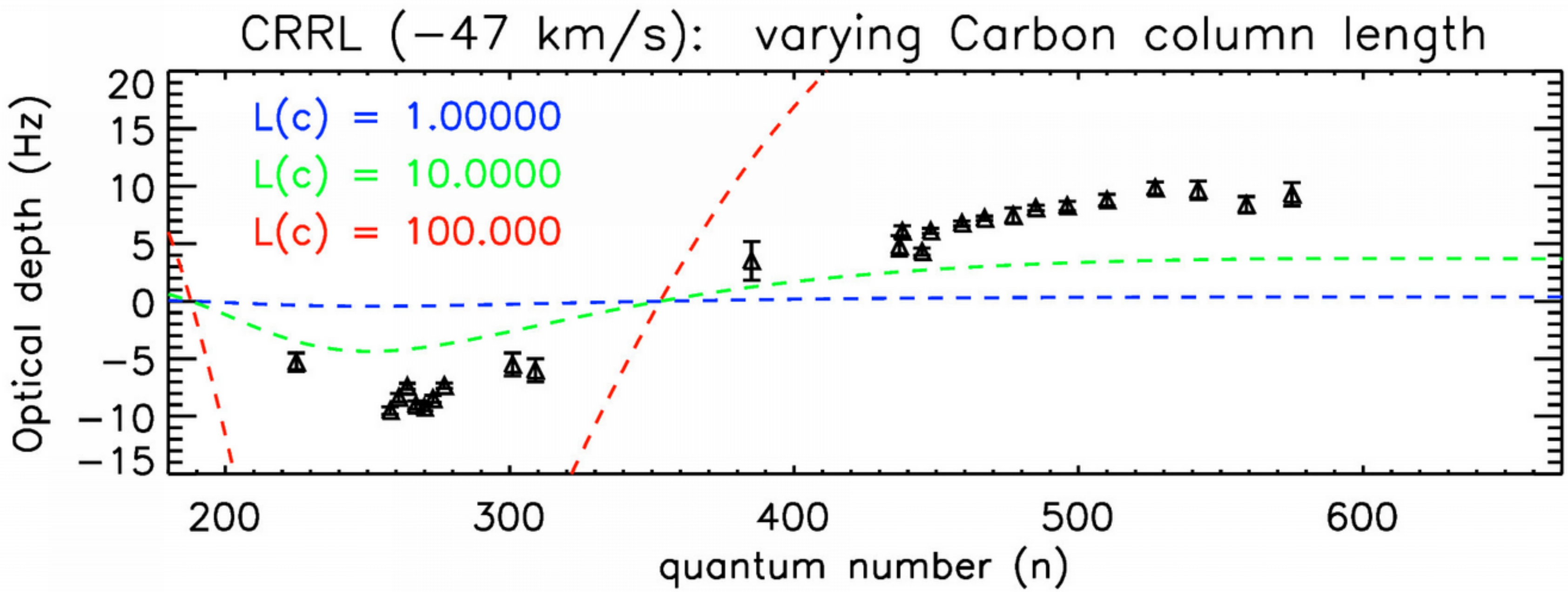


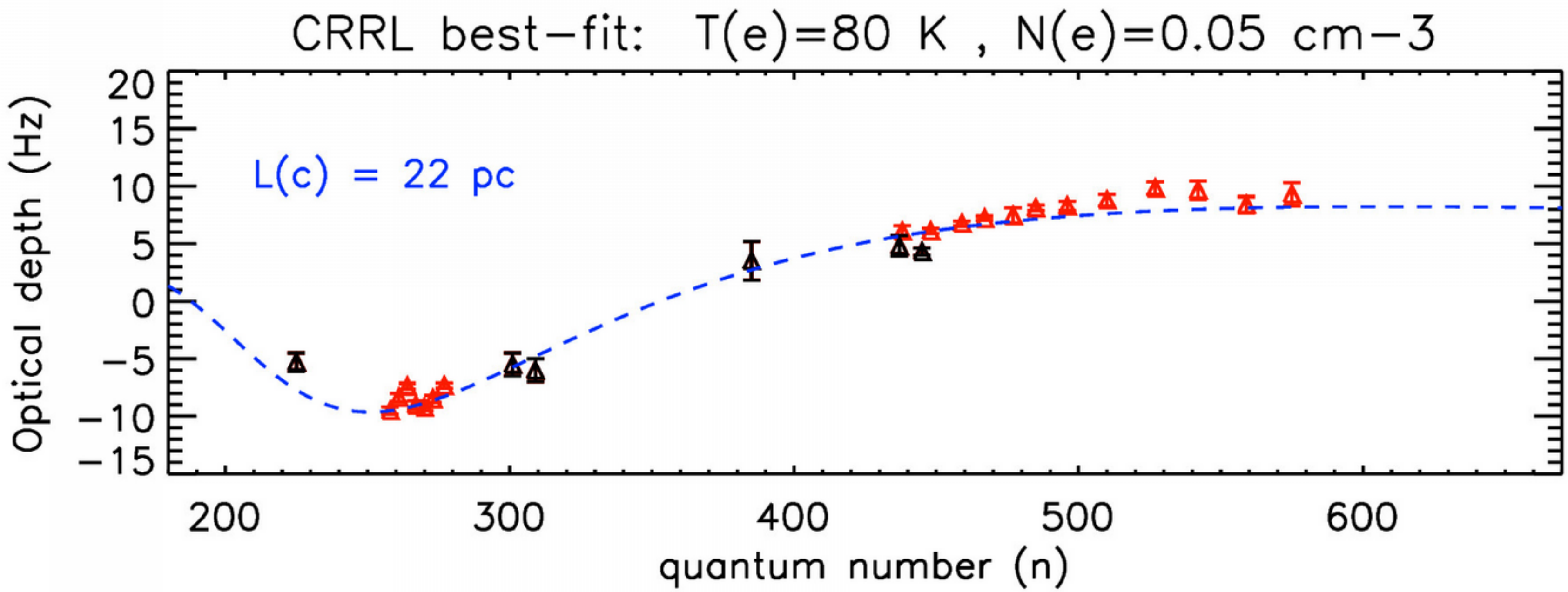
$$\Delta V_P \sim (n_e \, n^{5.2}) / (T_e^{1.5} \, \nu)$$

$$\Delta V_R \sim (T_R \, n^{5.8}) / \nu$$

[N(HI)=10^{20} cm^{-2}]

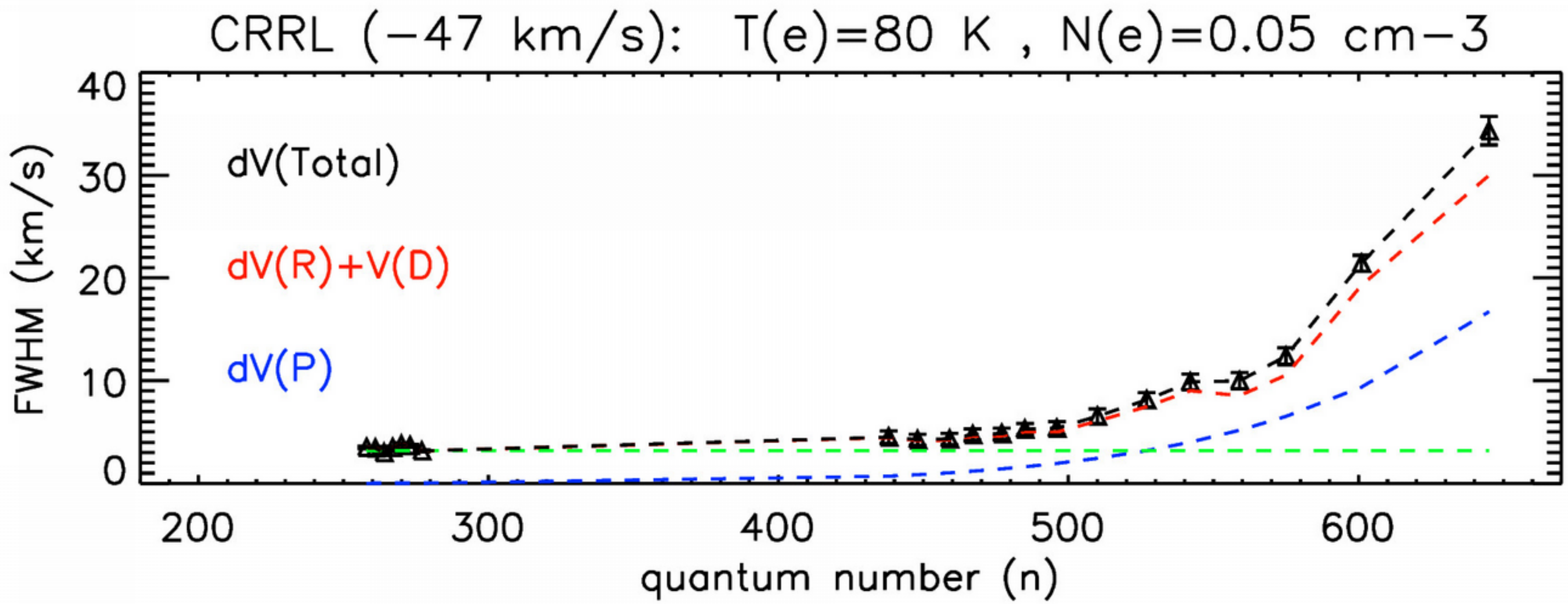
Cas A CRRL I: Optical depth (-47 km/s cloud)

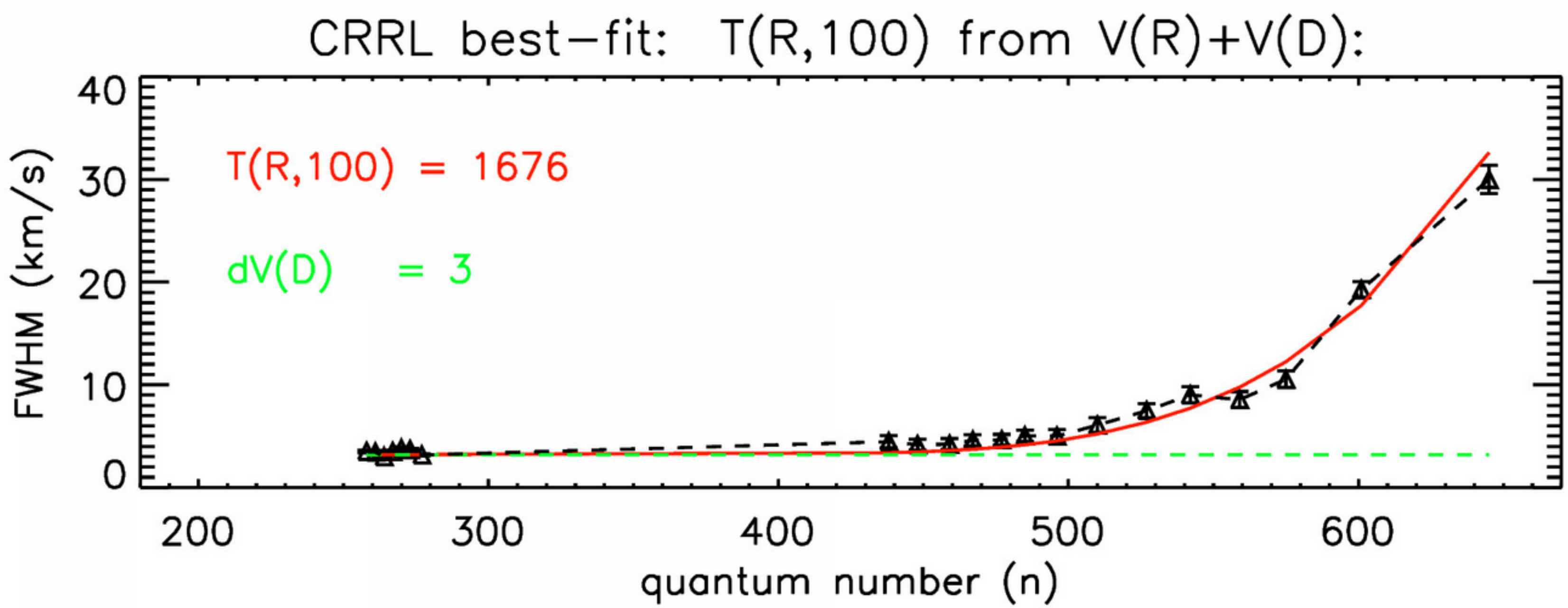




**** Parameters: T(e) , N(e) , L(c) , T(R)***

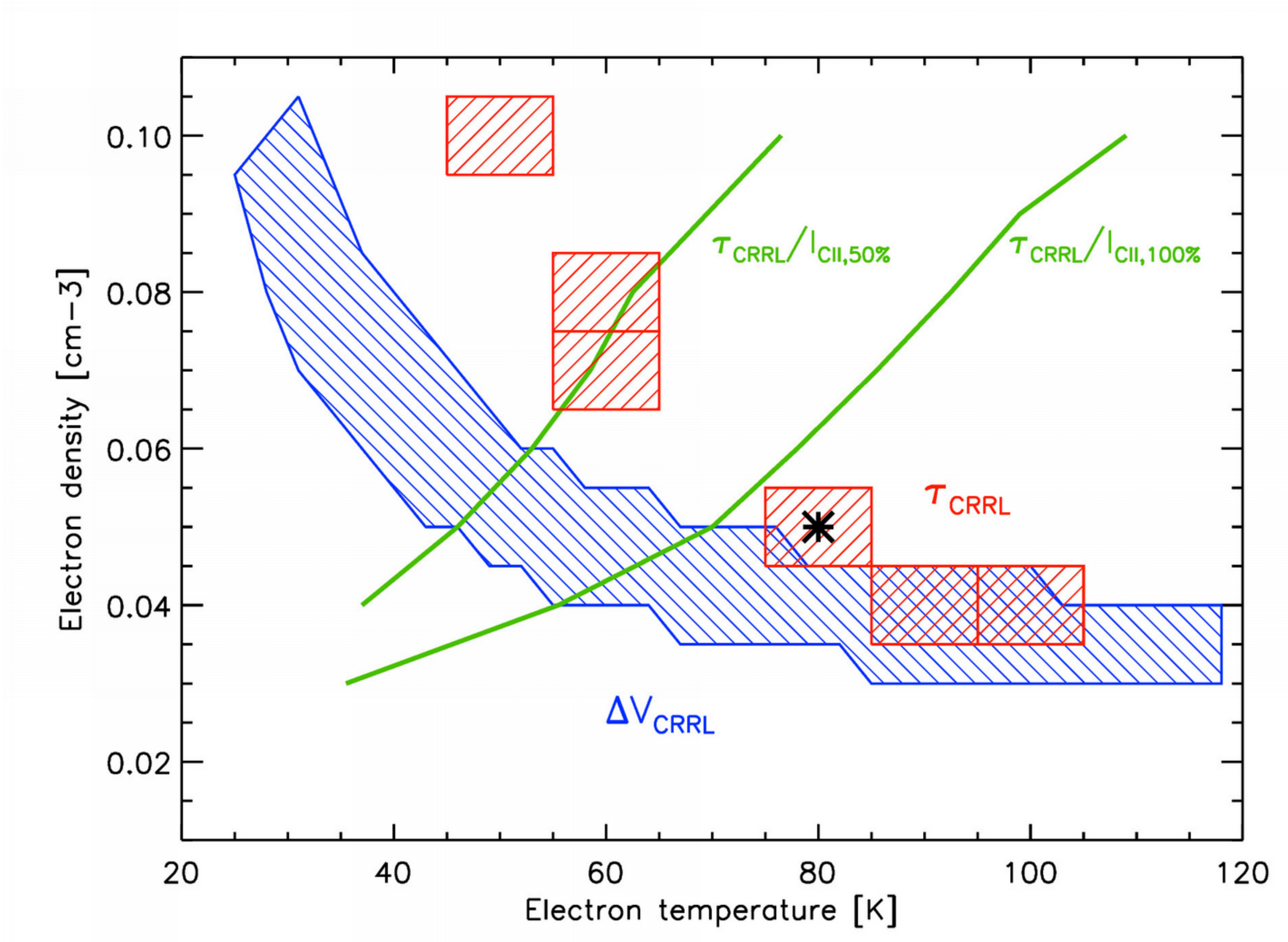
Cas A CRRL II: Line width (-47 km/s cloud)





**** Parameters: T(e) , N(e) , T(R)***

Cas A CRRL III: Putting it all together (-47 km/s cloud)



The Cassiopeia A clouds (-47, -38, 0 km/s).

“ Galaxy evolution is driven by recycling of the ISM ”

Cas A (diffuse) clouds & CRRL's

- **Thermal properties of RRL gas** *(T_e , n_e , L_C , T_R)*

  T(e) ~ 80 K , N(e) ~ 0.05 cm-3 , L(c) ~ 22 pc , T(R) ~ 1600 K

- **Ionization rate of the RRL gas** *(ζ_H)*

  ζ(H) ~ 4 x 10^{-17} s^{-1} { N(C+)/N(p) ~ 4 , N(C+)/N(e) ~ 0.8 }

- **Carbon abundance** *([C/H])*

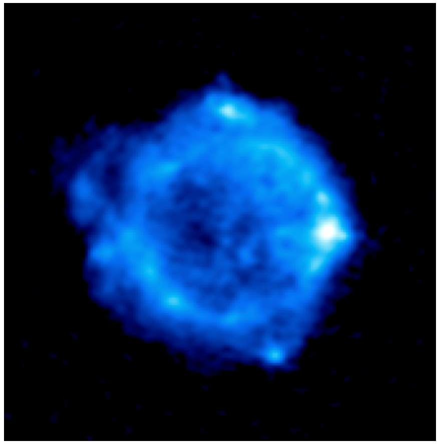
  [C/H] ~ 2.2 x 10^{-4}

- **Kinematics of the RRL gas** *(v , Δv)*

  3 clouds (-47, -38, 0 km/s), potentially -42 km/s

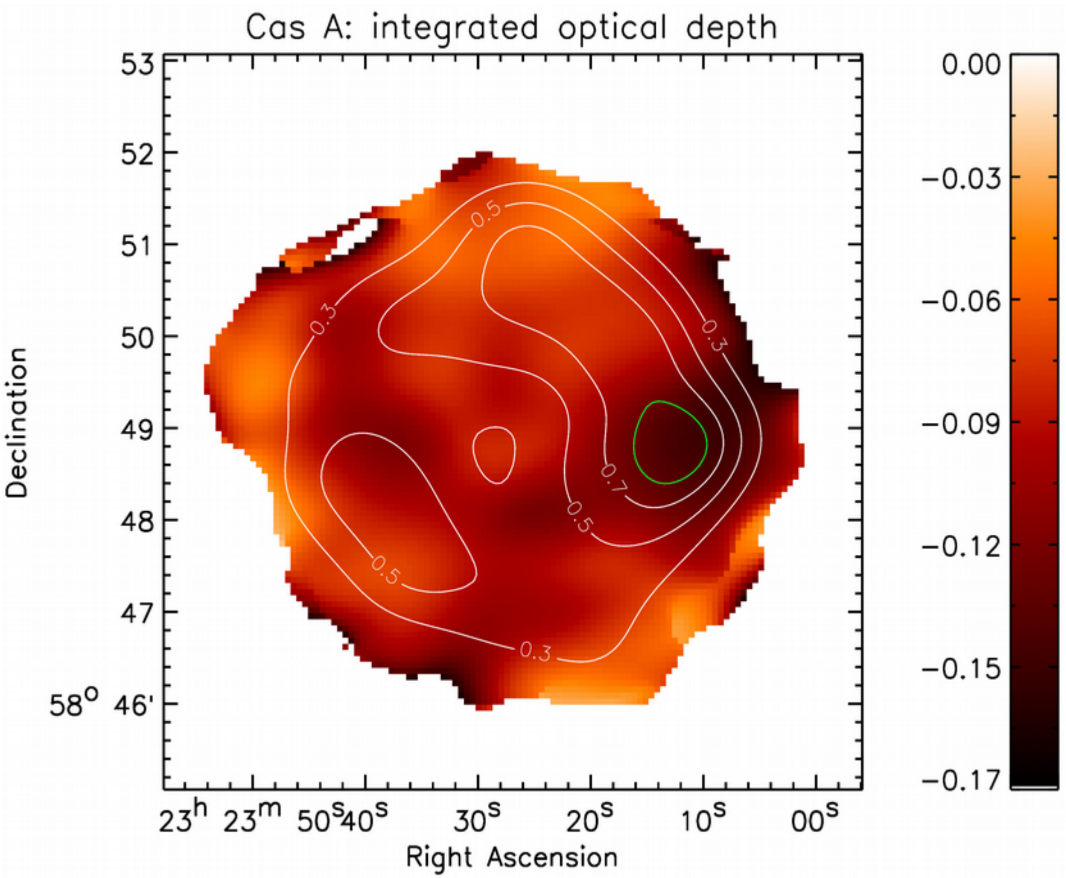
- **Localize RRL gas and compare w. CO, HI, HII**

  ... Salas et al. (in prep.)

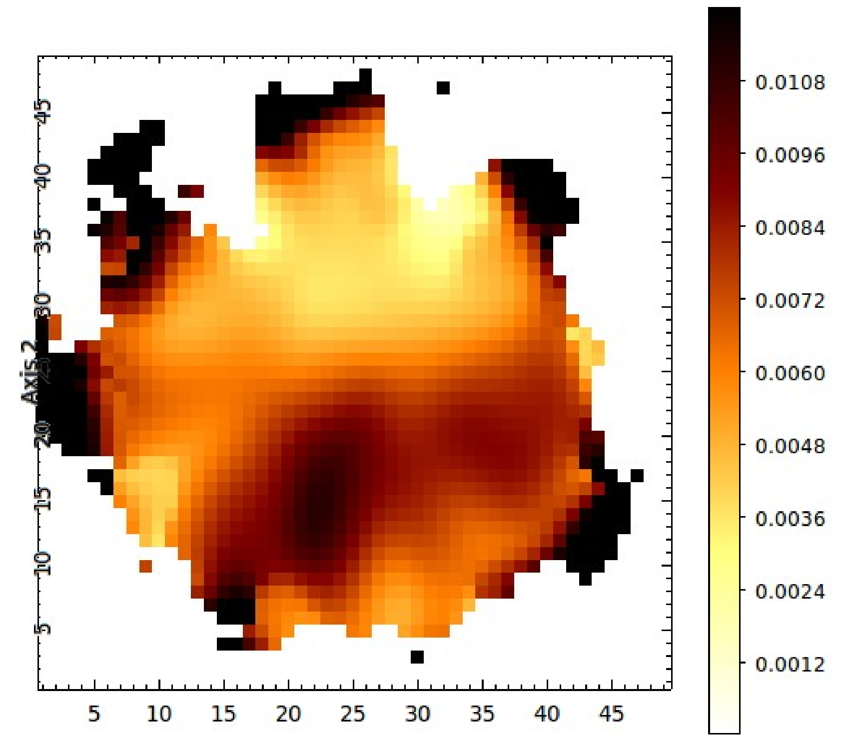


Work in progress I: (Cas A spatial distribution)

(LOFAR 33-56 MHz)



(WSRT 310-390 MHz)

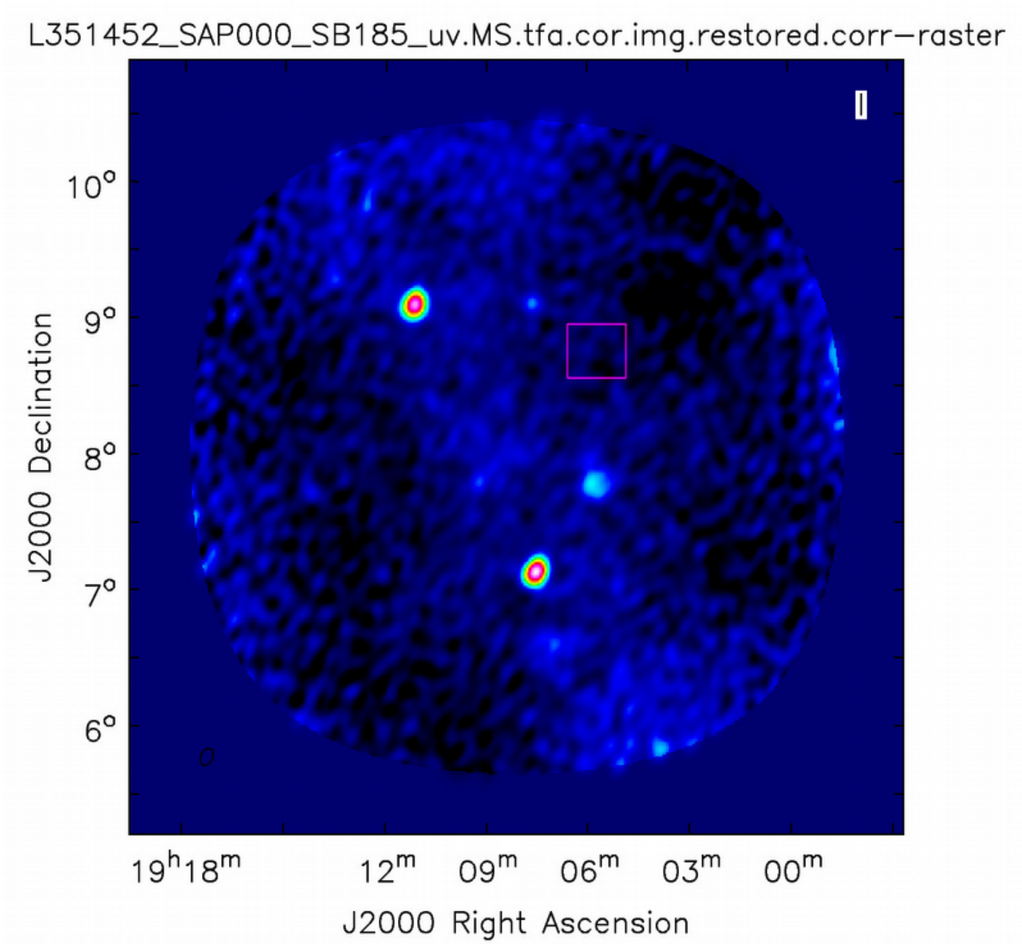


=> spatial CRRL variations w. frequency – changes in physical conditions ?

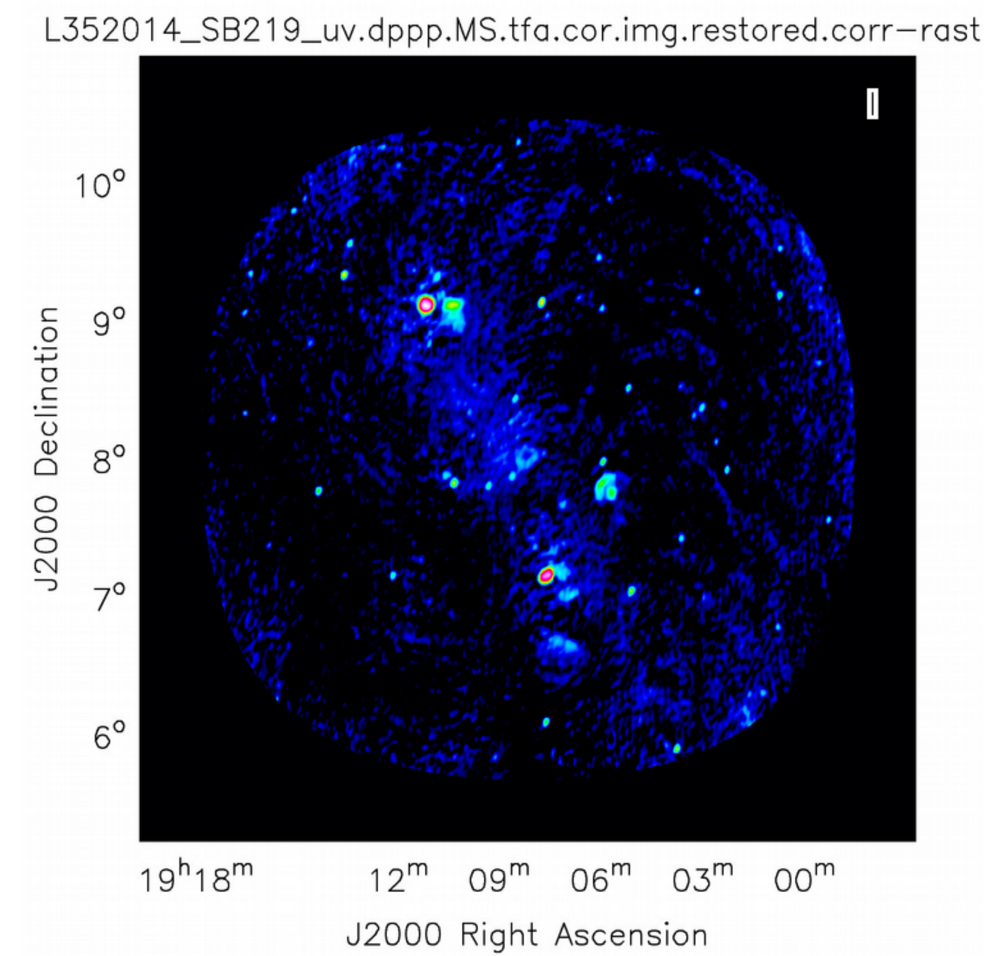
(Salas+ in prep)

Work in progress II: (MW plane Cycle 4 data)

(LOFAR CORE LBA: 1 SB)



(LOFAR CORE HBA: 1 SB)



=>   note : no phase calibration has been done (yet)
note : problems C4 MS data and CASACORE2

(Oonk+ in prep)

<u>Cas A CRRL III</u>:   Discriminating low vs. high T(e)