Low-frequency Galactic RRL's

" an observers perspective "

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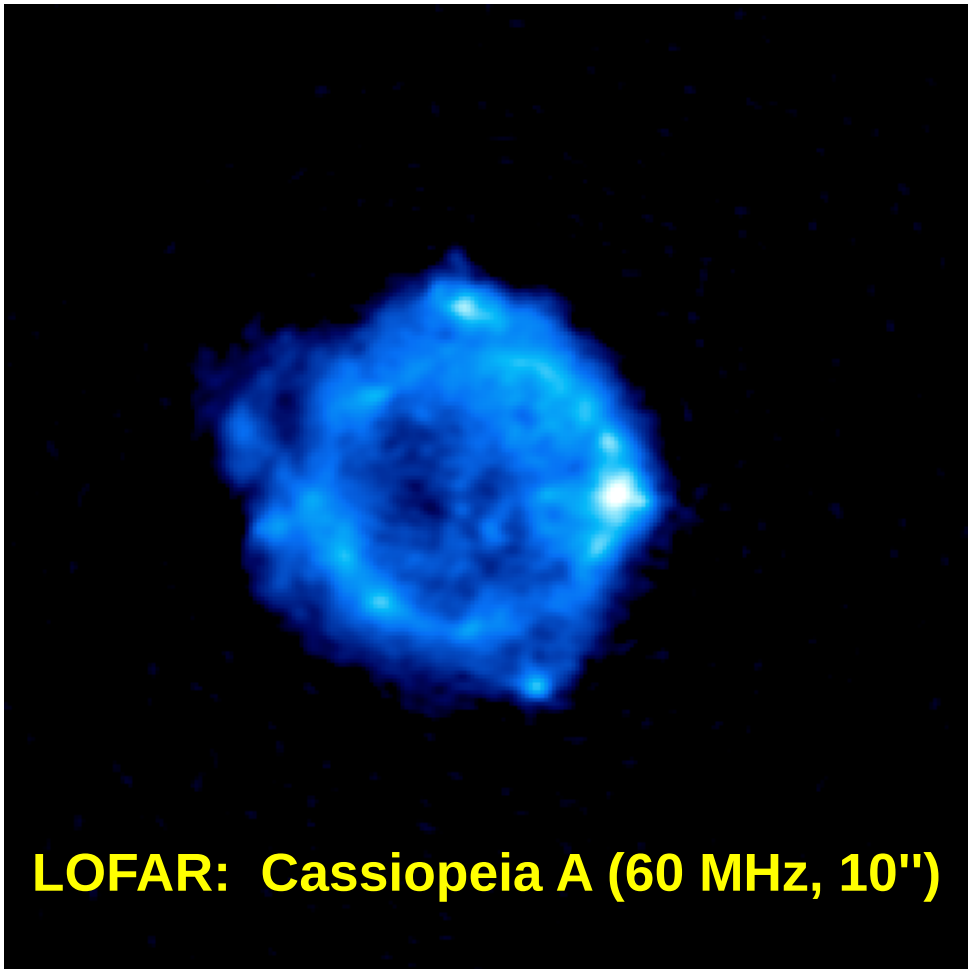
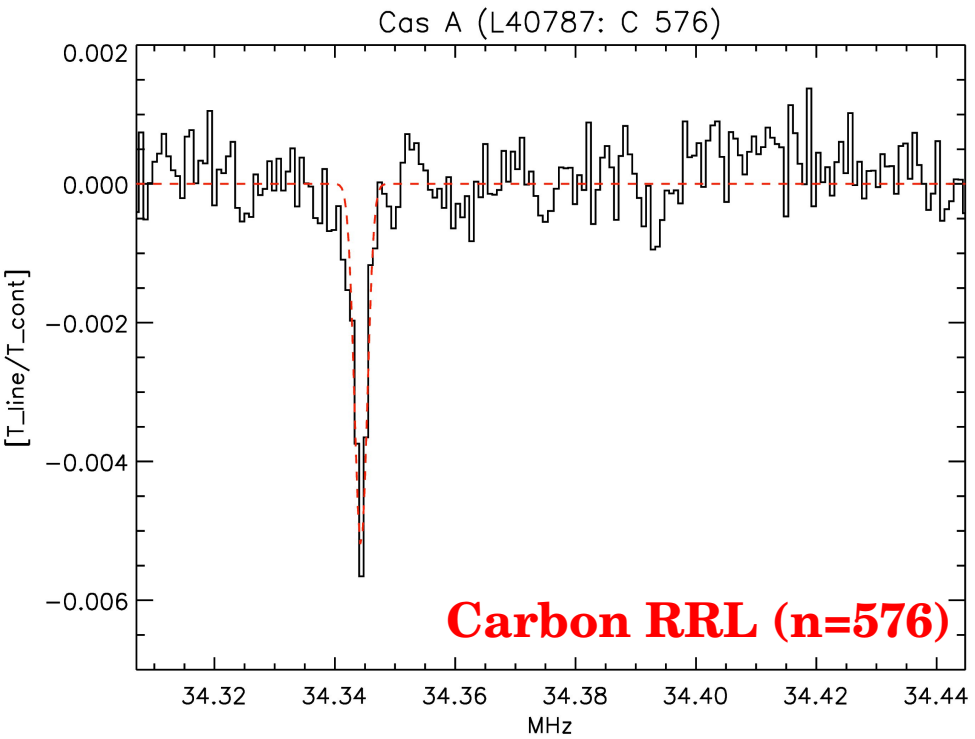
+ J. McKean , R. Fallows & J. Hessels !!



(1) Interstellar medium

(2) LOFAR & RRL's

- Cassiopeia A



The Interstellar Medium (ISM)

Phase	T [K]	n_H [cm^{-3}]	H-state	X_e	Obsv.
HIM	10^6	0.003	H^+	1	X-ray, UV
WIM	10^4	0.04	H^+	1	UV-IR
WNM	8000	0.1	H^0	0.1	HI (em)
CNM (HI)	100	50	H^0	$<10^{-3}$	HI (abs)
CNM (H_2)	30	>1000	H_2	$<10^{-7}$	CO

Galaxy evolution is driven by (SF) recycling of ISM

=> ***What is the role of the atomic CNM ?***

=> ***HI em (contaminated), HI abs (difficult)***

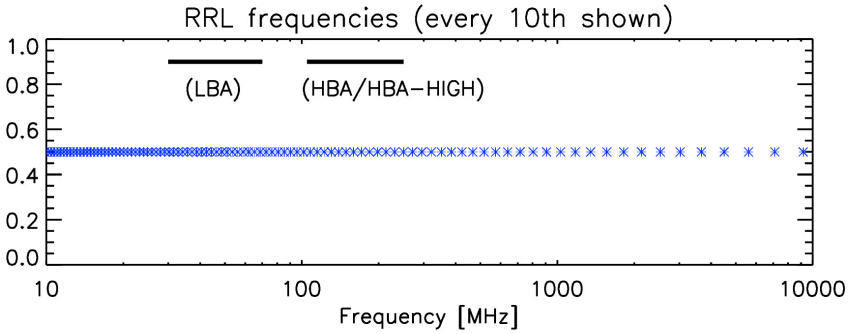
Radio Recombination Lines (RRL's)

" Spectral lines from ions recombining with electrons in a diffuse ionized plasma are called recombination lines "

- **Occur at all quantum levels (n):** $\nu = R\,c\,[\,1/n^2 - 1/(n+\Delta n)^2\,]$

  n < 50: **UV-IR (RL)**

  n > 50: **Radio (RRL)**



- **RRL types:**

  classical **(ν > 1 GHz)** ***"Palmer & Zuckerman 1966"***

  diffuse **(ν < 1 GHz)** ***"Konovalenko & Sodin 1980"***

- **Diffuse RRLs:**

  - weak **(Milky Way – τ_{peak} ~$10^{-(3\text{-}4)}$)**

  + many **(500 α lines – LOFAR)**

Diffuse RRL's (≤ 1 GHz)

- Carbon, (Hydrogen) RRL's

  Absorption ≤ 130 MHz
  Emission ≥ 130 MHz *Stimulated emission (Goldberg 1966)*

- Associated with CNM / PDR's

  T_e ~ 10-300 [K]
  n_e ~ 0.01-1.0 [cm^{-3}]

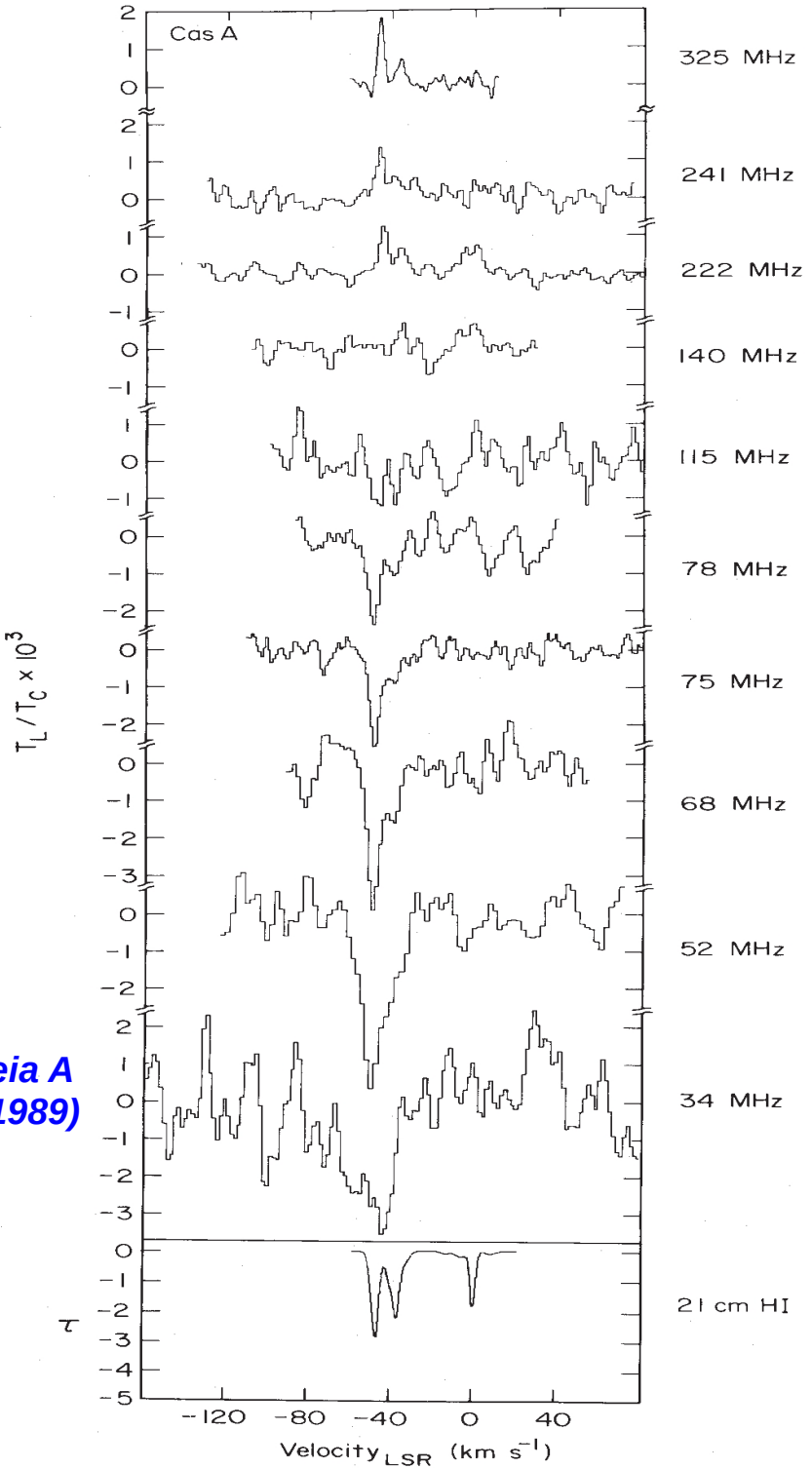
- properties : T_e , n_e , EM

- ionisation : ζ(H)

- metallicity : [C/H]

- kinematics : v , Δv

(?) unstable gas : T ~ 500-5000 [K]
(%) WNM : T ~ 10000 [K]



Cassiopeia A (Payne+1989)

RRL models: Line width broadening

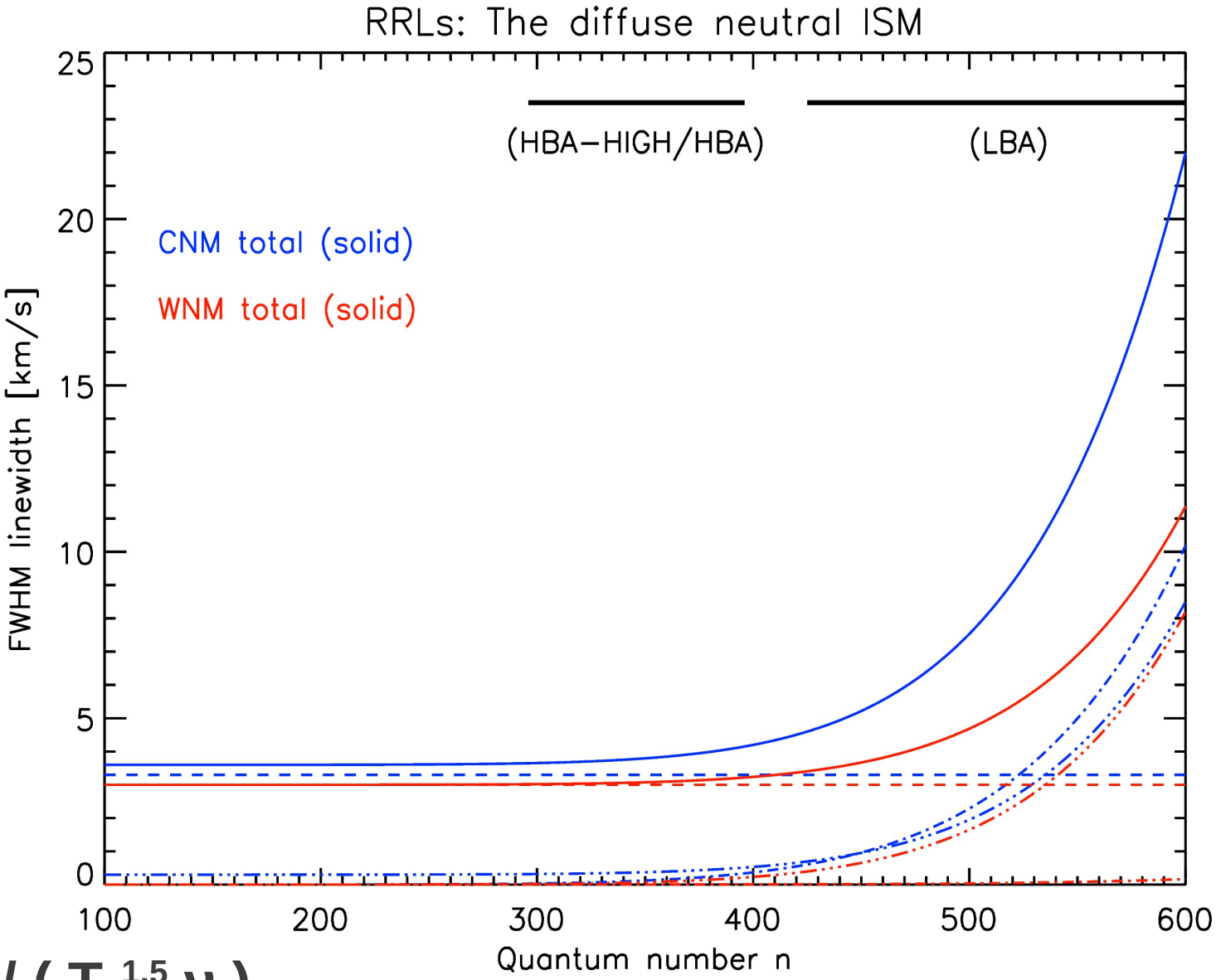
Total (solid) width

Contributions:

(1) Doppler (dash)

(2) Pressure (dash-dot)

(3) Radiation (dash-dot-dot)



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

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

RRL models: Integrated Optical Depth (τ)

Phase.

CNM (atomic):

- $n_e = 0.05\ cm^{-3}$
- $T_e = 100\ K$

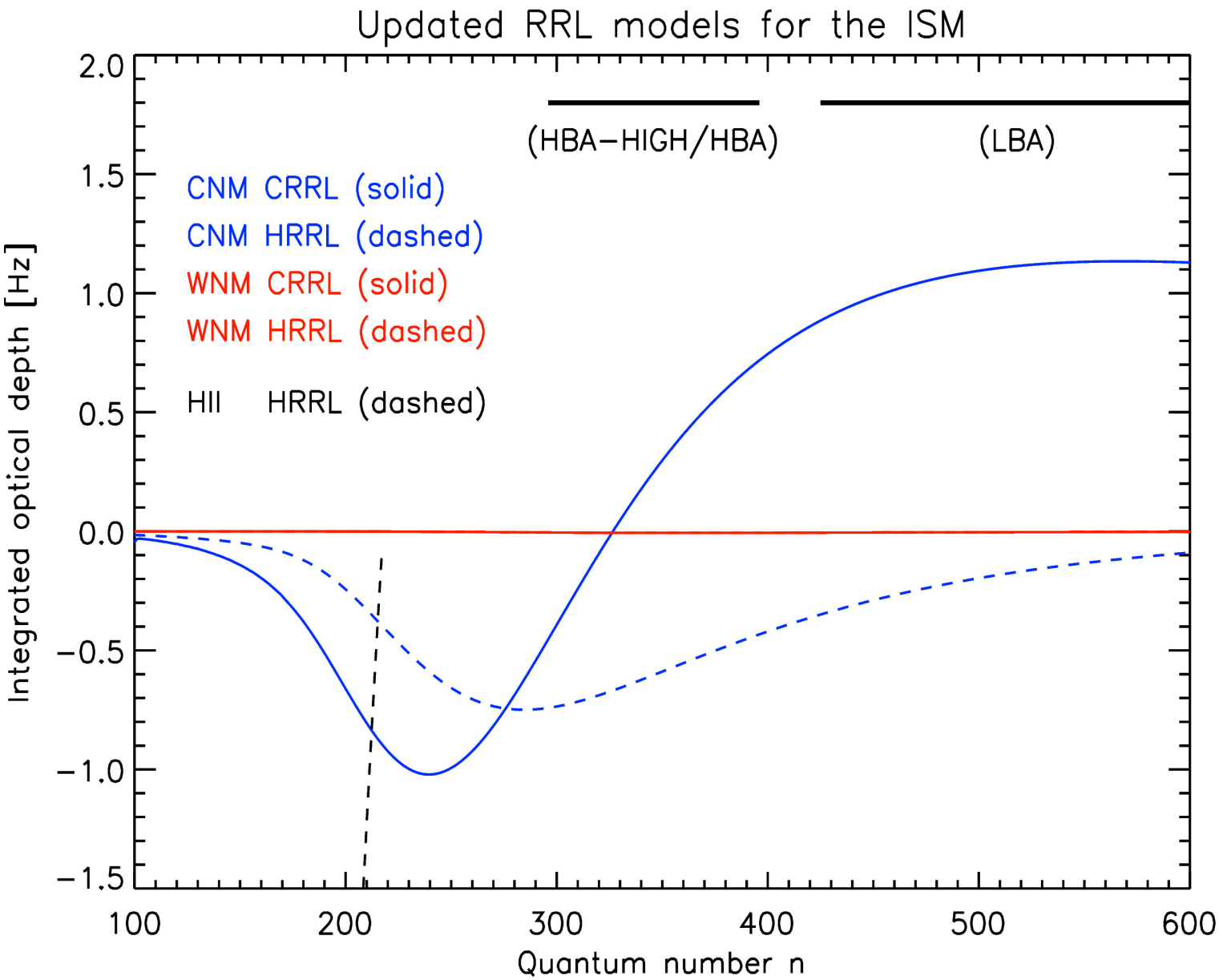
WNM:

- $n_e = 0.01\ cm^{-3}$
- $T_e = 10^4\ K$

HII:

- $n_e = 300\ cm^{-3}$
- $T_e = 10^4\ K$

**** use RRL to disentangle CNM, WNM in HI 21 cm***



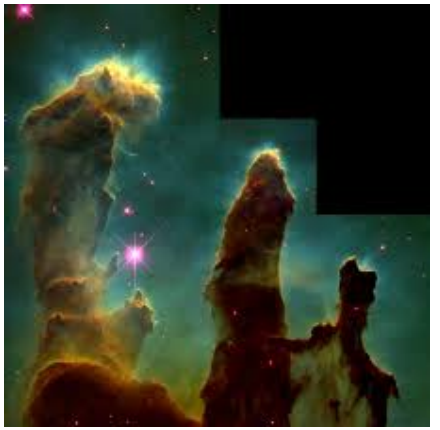
$$\tau_C \sim T_e^{-5/2}\ EM_C\ (\ b_n\ \beta_n\ )_C$$

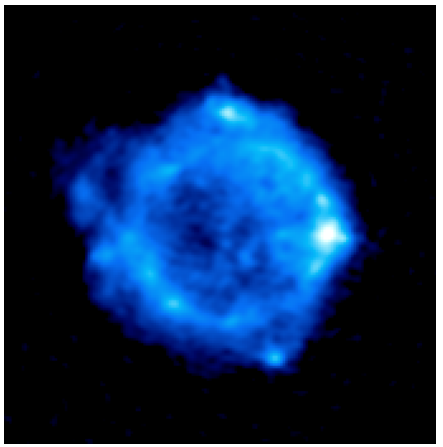
Returning to the BIG question.

" Galaxy evolution is driven by recycling of the ISM "

but,

what is the role of the cold atomic gas in galaxy evolution ?





Method : Low-frequency RRL's

- Localize RRL gas and compare w. CO, HI, HII
- Thermal properties of RRL gas (T_e , n_e , EM)
- Ionization rate of the RRL gas (ζ_H)
- Carbon abundance ([C/H])
- Kinematics of the RRL gas (v , Δv)

Diffuse Radio Recombination Lines with LOFAR

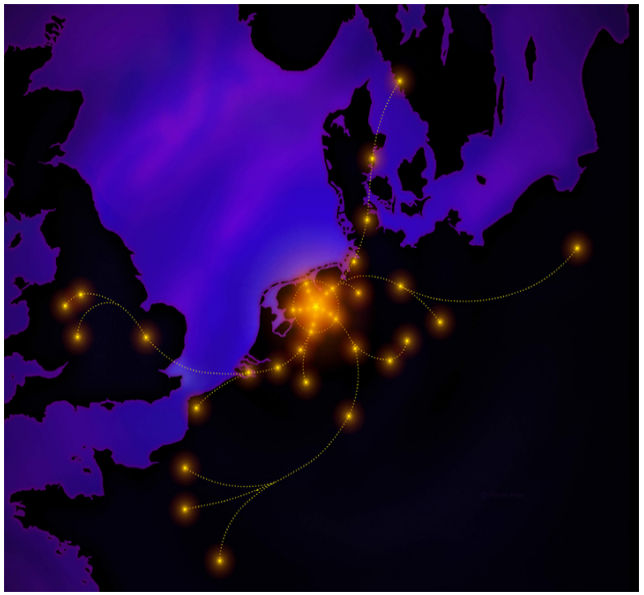
The Power of LOFAR:

- sensitivity
- **spatial, spectral resolution**
- field of view
- **frequency coverage**
- bandwidth

=> *"Survey speed"* (α , δ , λ)

* **LBA 10 - 70 MHz : 400 RRL α-lines**

* **HBA 105 - 250 MHz : 100 RRL α-lines**



Three RRL Surveys with LOFAR

(a) Medium resolution Galactic survey

- Morphology (deg to 10' scales)
- Thermal balance CNM
- Ionization rate CNM
- Carbon abund. (stellar evolution)

(b) High resolution Galactic follow-up

- Connect >10' to <1' scales
- SNR's (e.g. Cassiopeia A)

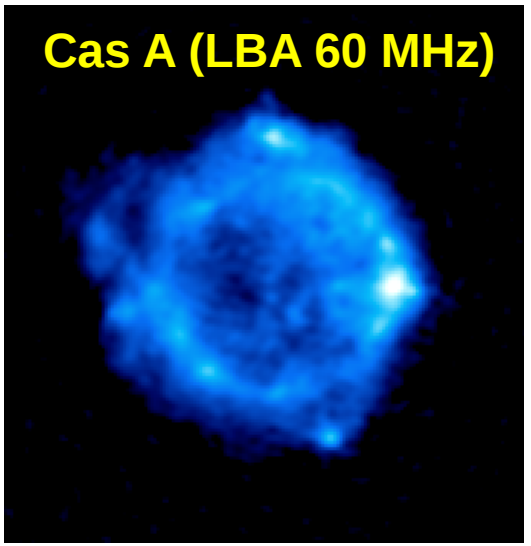
(c) Extragalactic survey

- Trace RRL/CNM in other galaxies
- Bright radio sources (>10 Jy)

Conclusions & Outlook

ASTRON

$LOFAR\text{-}RRL \Rightarrow \underline{CNM}\ (T_e, n_e, EM, \zeta_H, [C/H])$



(a) Scientific:

- LOFAR can map the CNM in the Milky Way
- Bright (background) sources give < 1' scale

(b) Technical:

- Spectroscopic results stable (>2 years)
- Spectral RMS: √(time) , √(chan) , √(#SB)

LOFAR

(c) Future:

- LOFAR cycle 1... (stay tuned)
- SKA-low (10xLOFAR)