



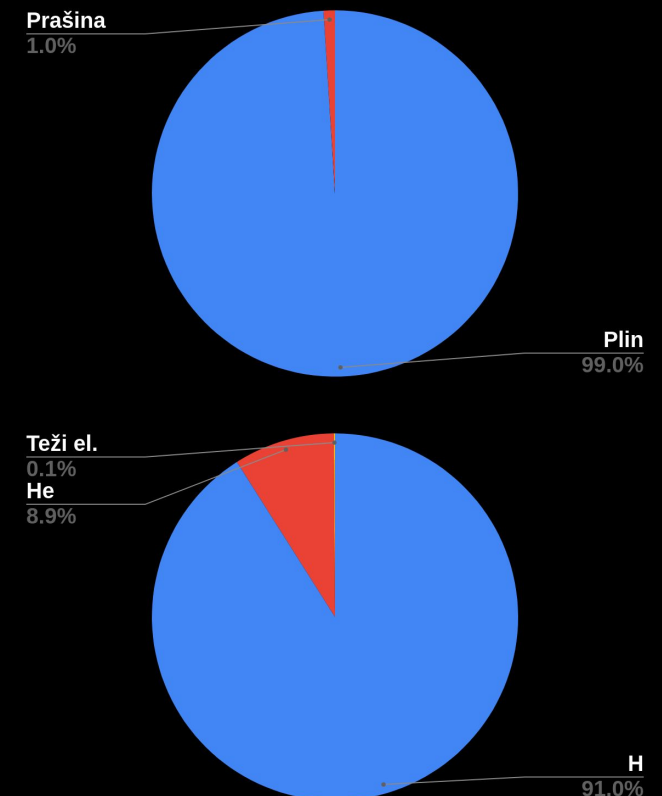
Neutralna međuzvezdana materija u Mliječnoj Stazi

Povezivanje simulacija i opažanja

Međuzvezdana materija

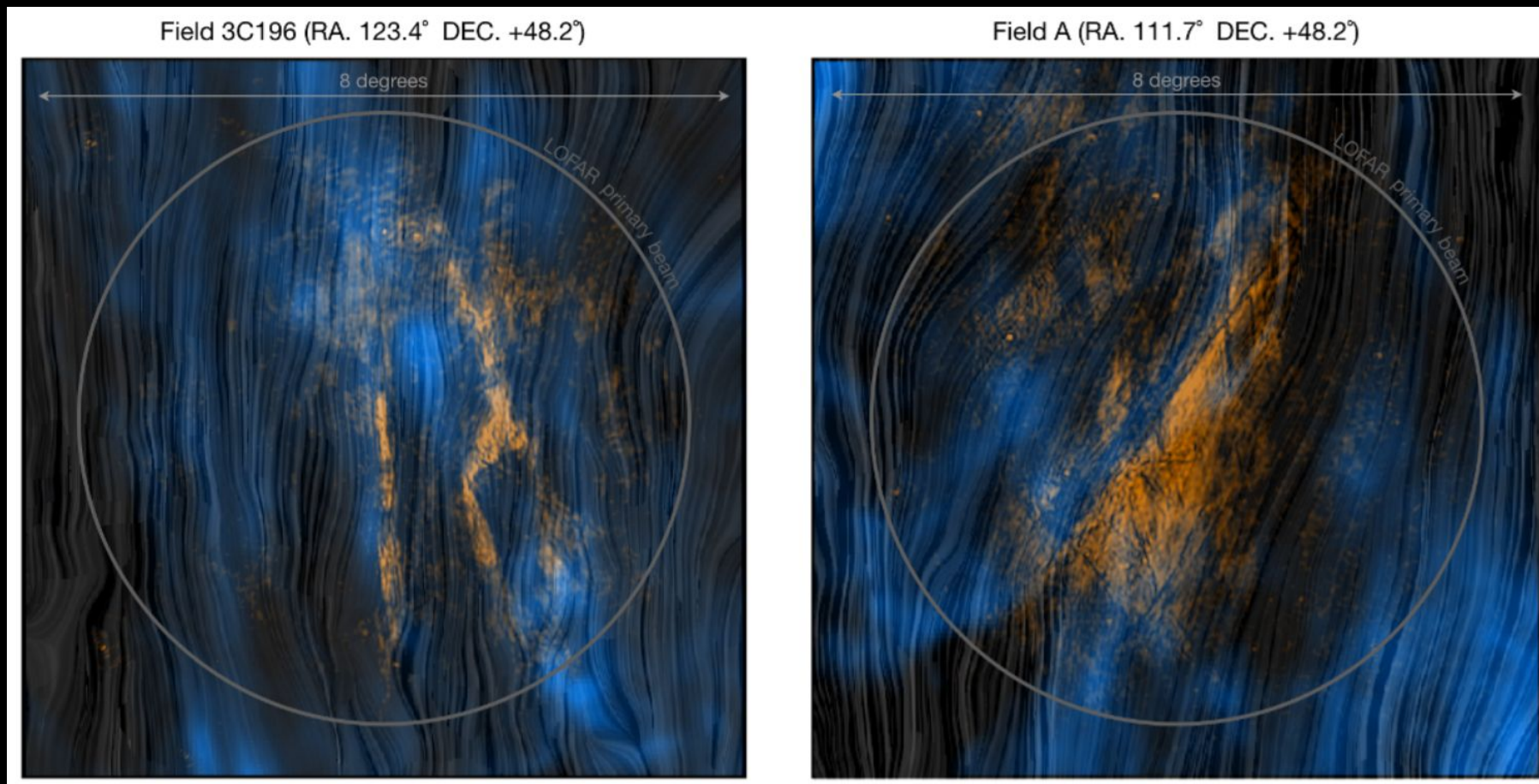
- ❖ Ionizirani, atomski i molekularni plin, prašina i kozmičke zrake
- ❖ Nekoliko faza s obzirom na temperaturu i gustoću
- ❖ Numeričke simulacije: magnetohidrodinamika (MHD)
 - ❖ Visok stupanj nelinearnosti

Faza	T [K]	n [cm ⁻³]
Vruća ionizirana materija (<i>hot ionized medium; HIM</i>)	$\sim 10^6$	$\sim 10^{-2}$
Topla ionizirana materija (<i>warm ionized medium; WIM</i>)	$\sim 5 \cdot 10^3$	~ 0.5
Topla neutralna materija (<i>warm neutral medium; WNM</i>)	$\sim 5 \cdot 10^3$	$\sim 0.5 - 2$
Hladna neutralna materija (<i>cold neutral medium; CNM</i>)	$\sim 10^2$	$\sim 10^2$
Molekularni oblaci (<i>molecular clouds</i>)	~ 10	$\sim 10^3$



Motivacija

❖ Međuzvezdani plin: neutralni i ionizirani



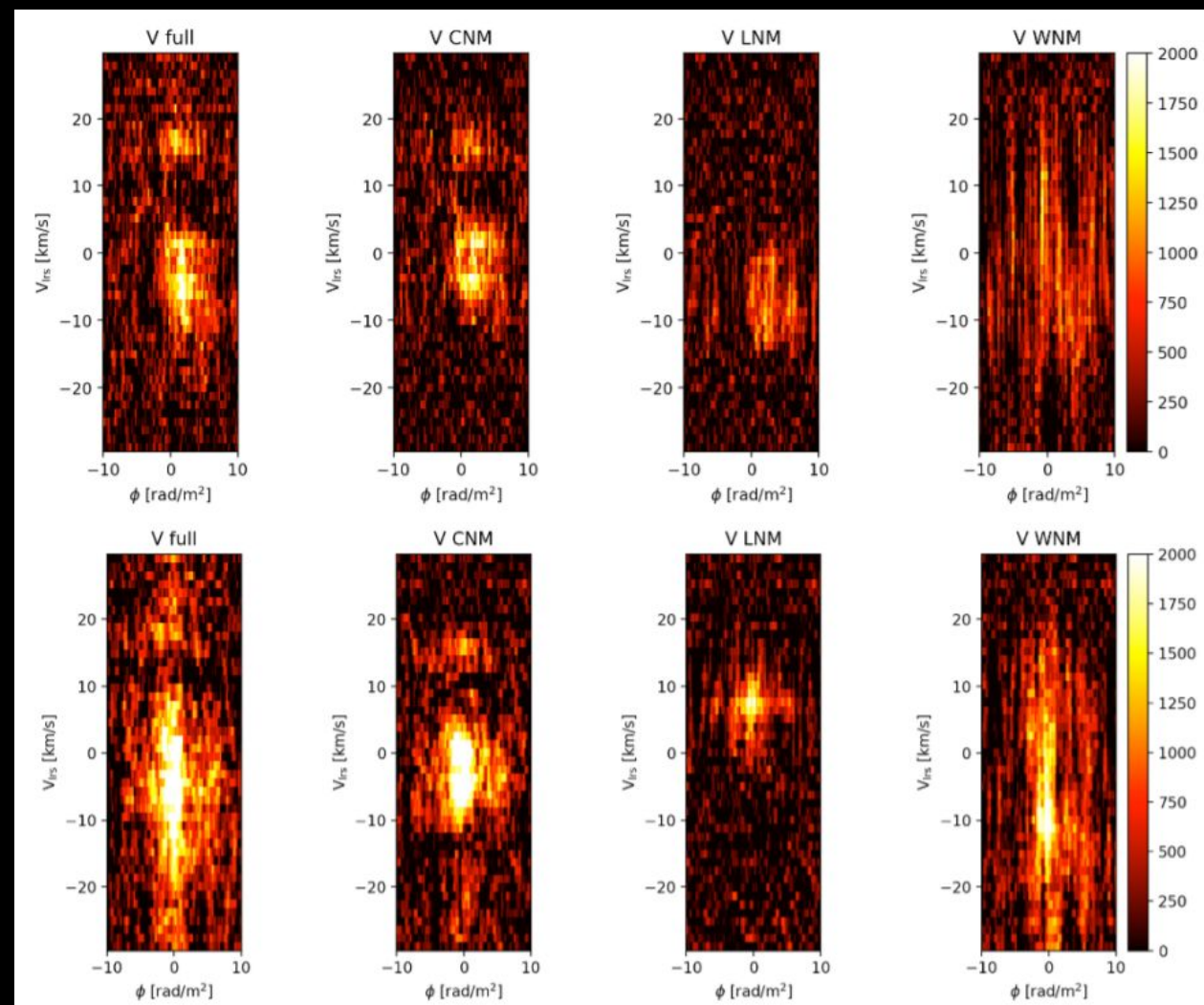
[Izvor: A. Bracco et al., A&A, 2020]

Motivacija

❖ Faze neutralne materije:

- topla (WNM)
- mlaka (LNM)
- hladna (CNM)

❖ Najjača korelacija s hladnom materijom



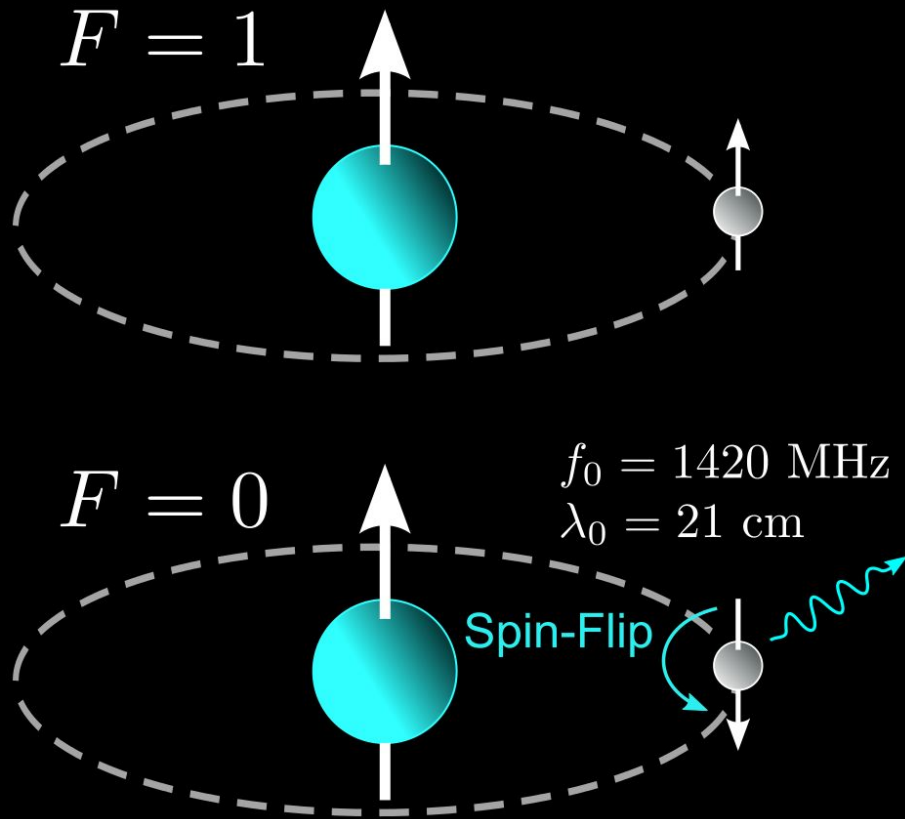
[Izvor: A. Bracco et al., A&A, 2020]

Numeričke simulacije

- ❖ MHD simulacije
- ❖ Pokazuju najveću korelaciju s toplom materijom
- ❖ Pitanje: Je li rastav faza iz mjerenja konzistentan?

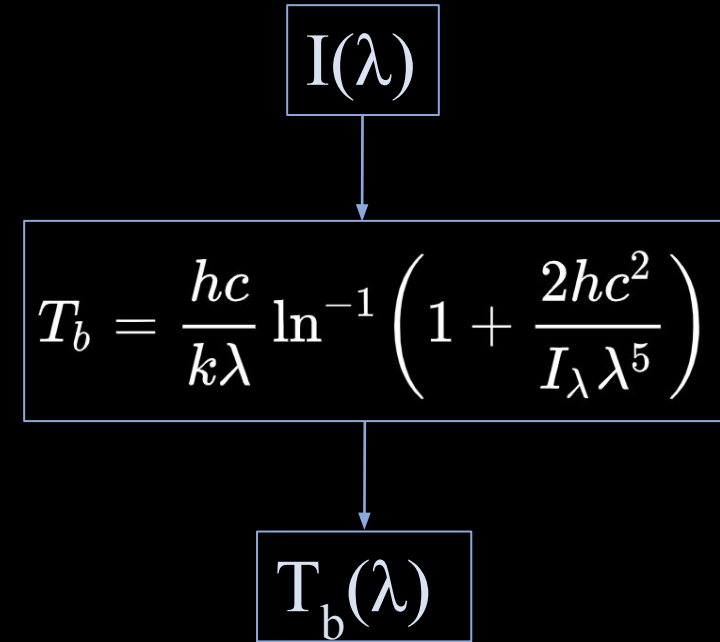
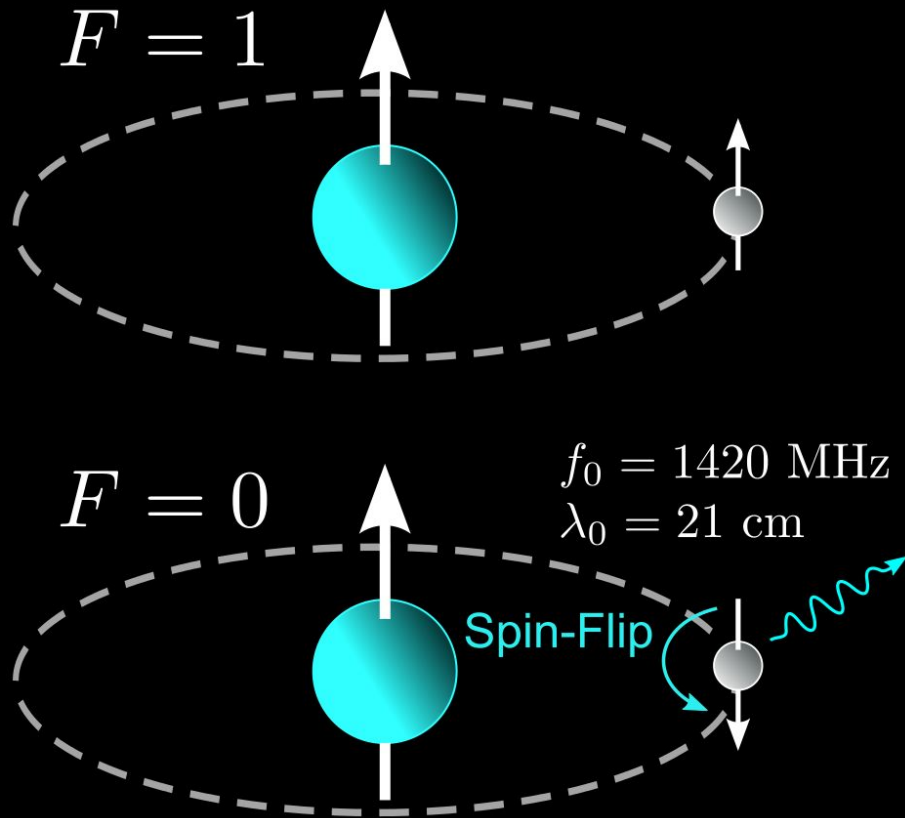
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Detekcija neutralnog vodika



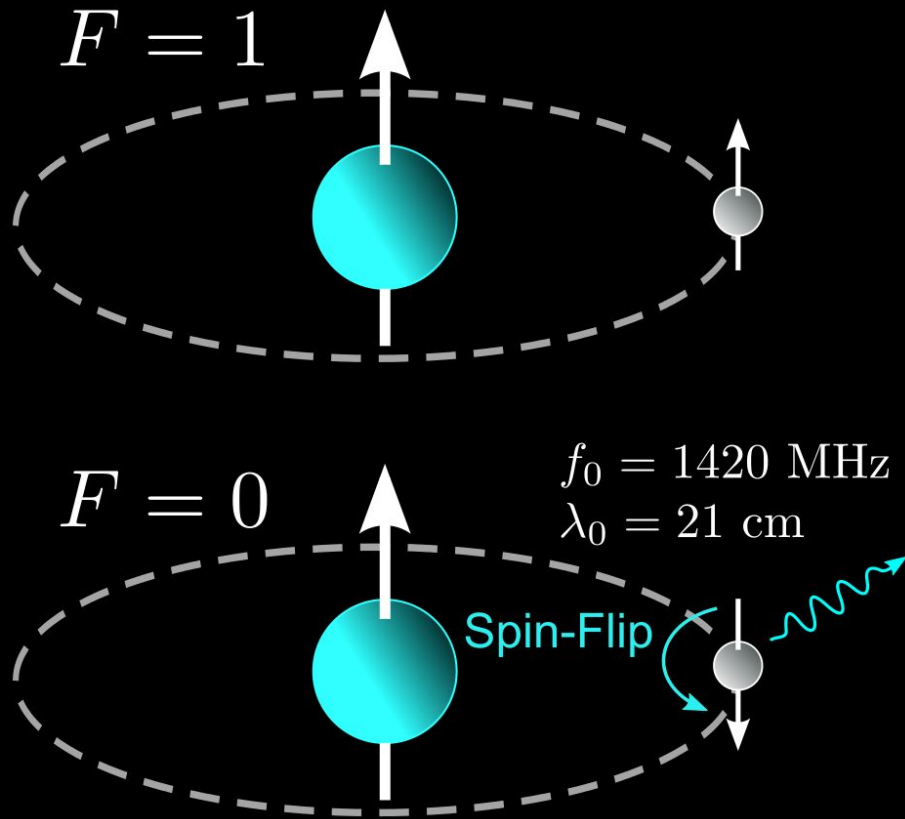
[Izvor: https://en.wikipedia.org/wiki/Hydrogen_line#/media/File:Hydrogen-SpinFlip.svg]

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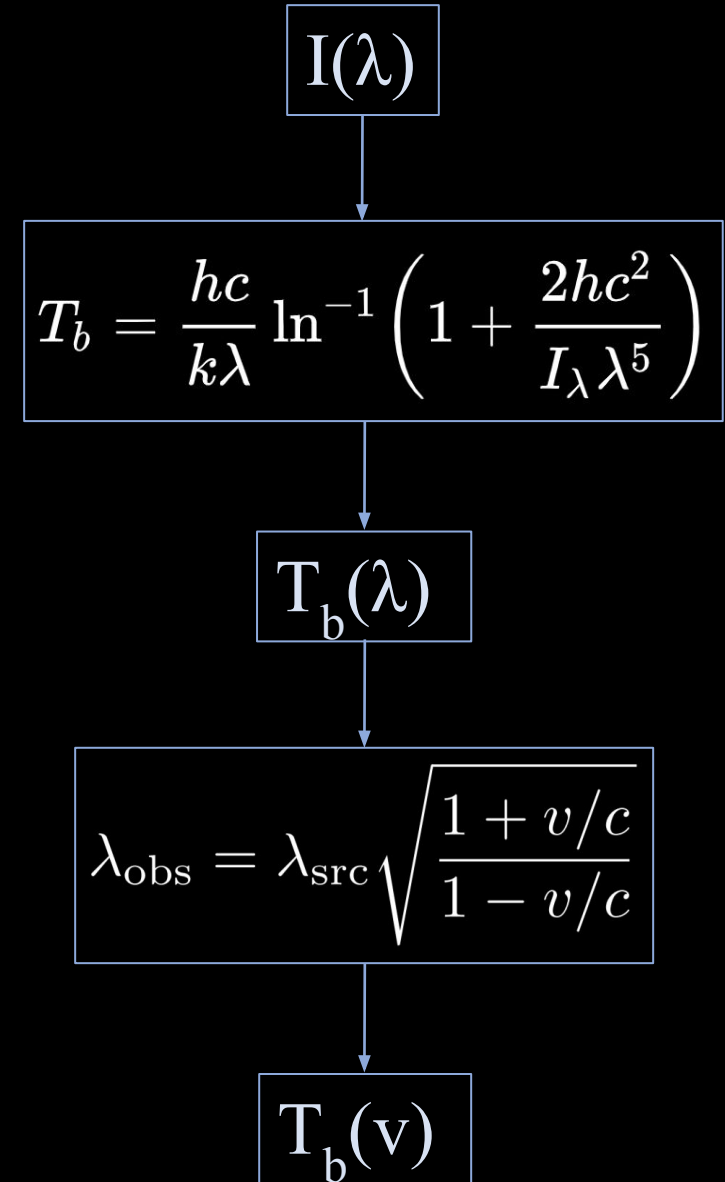


[Izvor: https://en.wikipedia.org/wiki/Hydrogen_line#/media/File:Hydrogen-SpinFlip.svg]

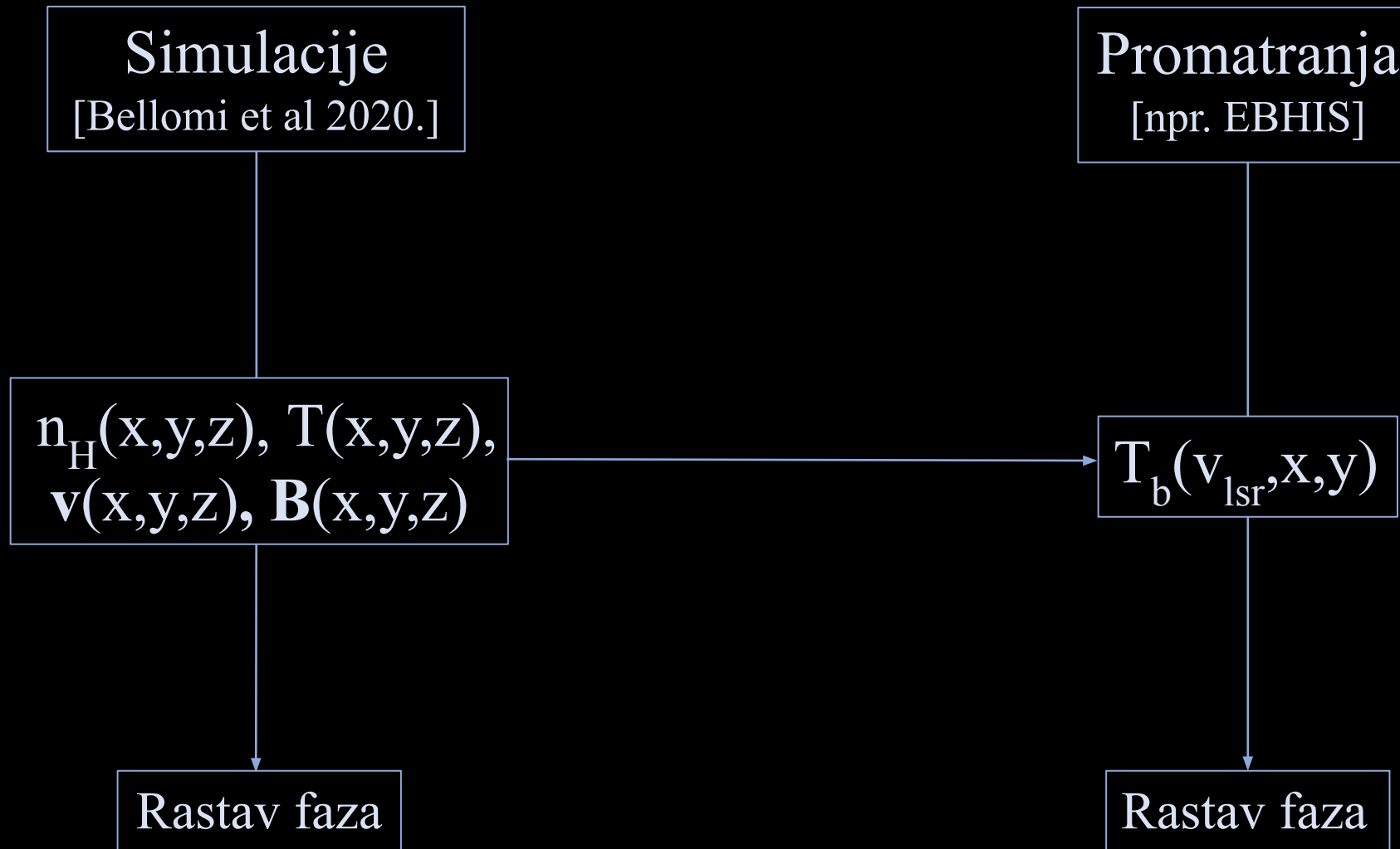
Detekcija neutralnog vodika



[Izvor: https://en.wikipedia.org/wiki/Hydrogen_line#/media/File:Hydrogen-SpinFlip.svg]



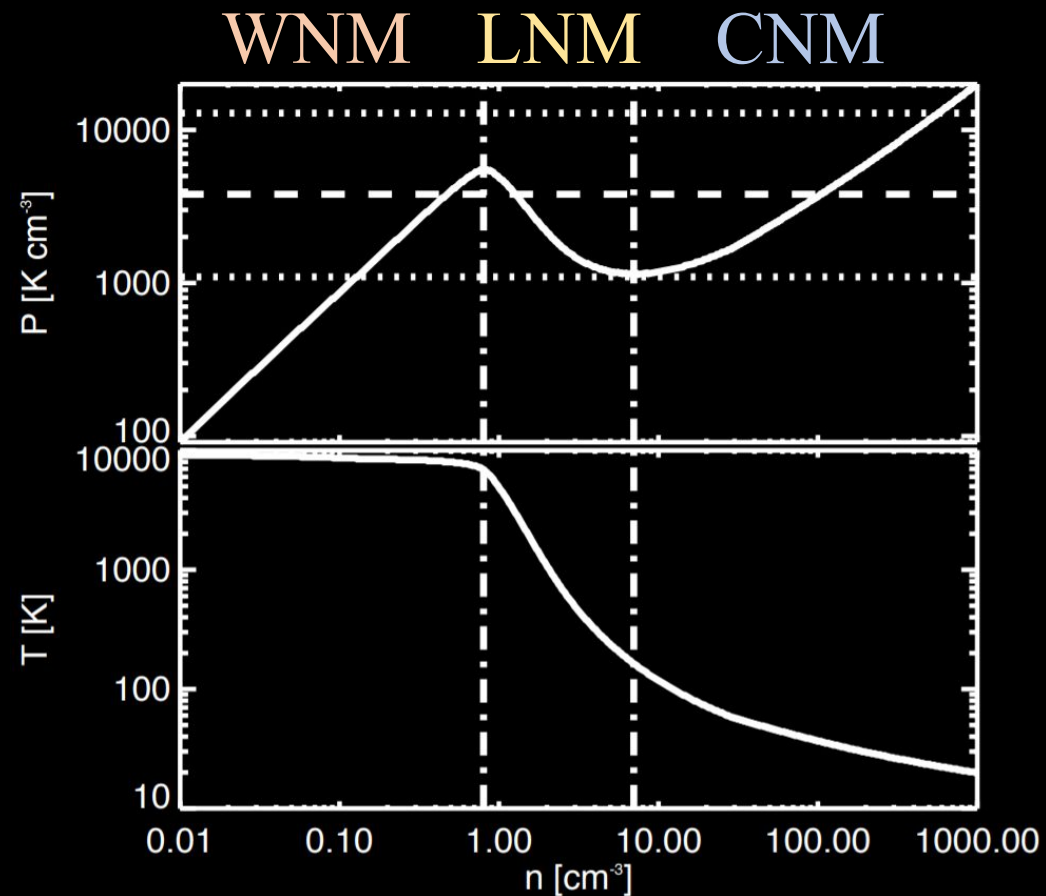
Cilj



Simulacije

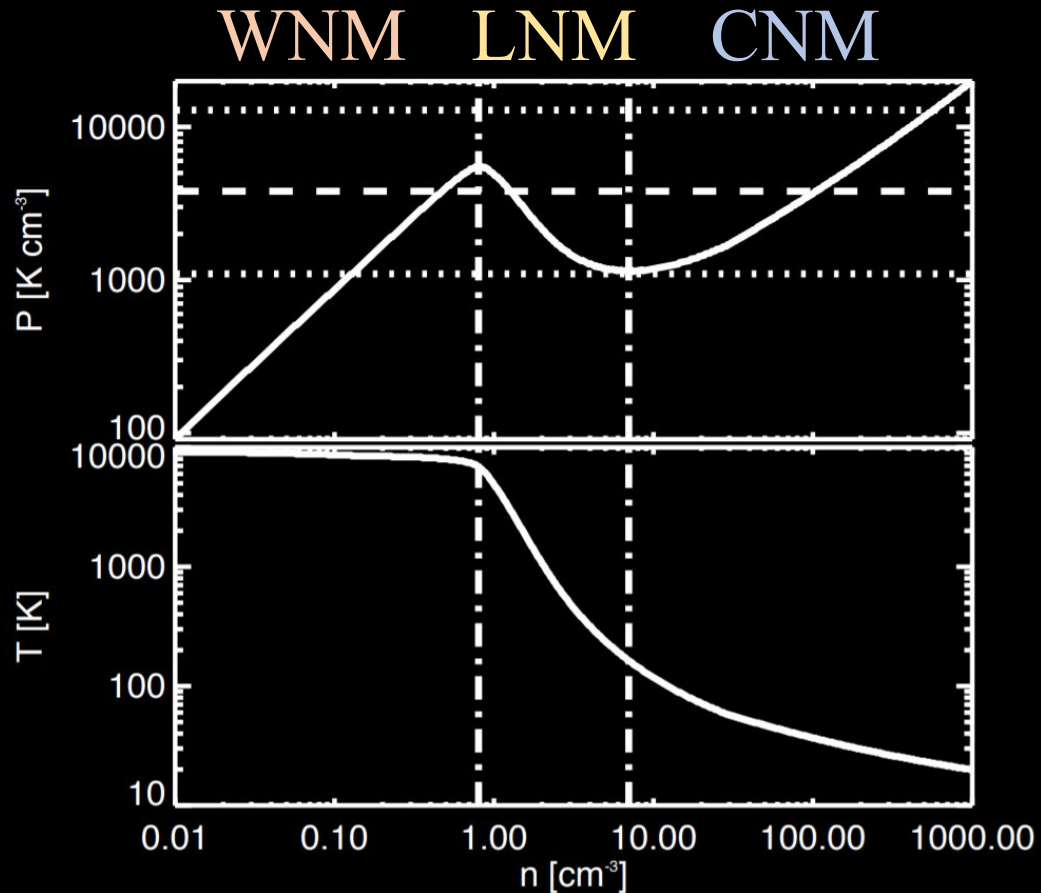
- ❖ Bellomi et al. 2020.
- ❖ RAMSES
- ❖ 128^3 piksela; $L = 50$ pc
- ❖ Izotropni spektar UV zračenja
- ❖ Početni uvjeti:
 - $B_0 = 3.8 \mu\text{G}$
 - $G_0 = 1$ Habing
 - $\xi_0 = 0.5$

Faze neutralne materije

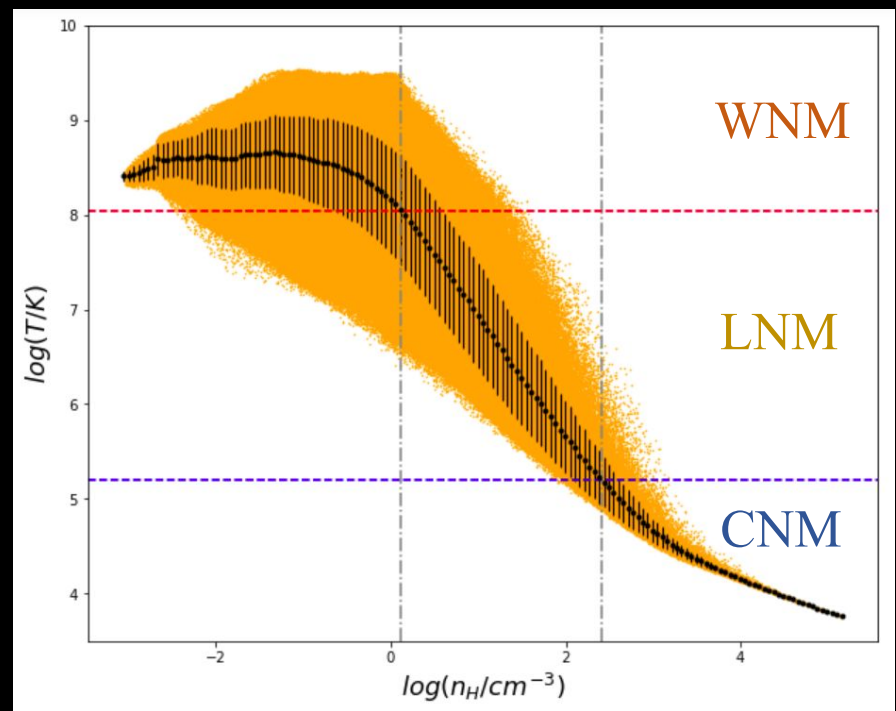
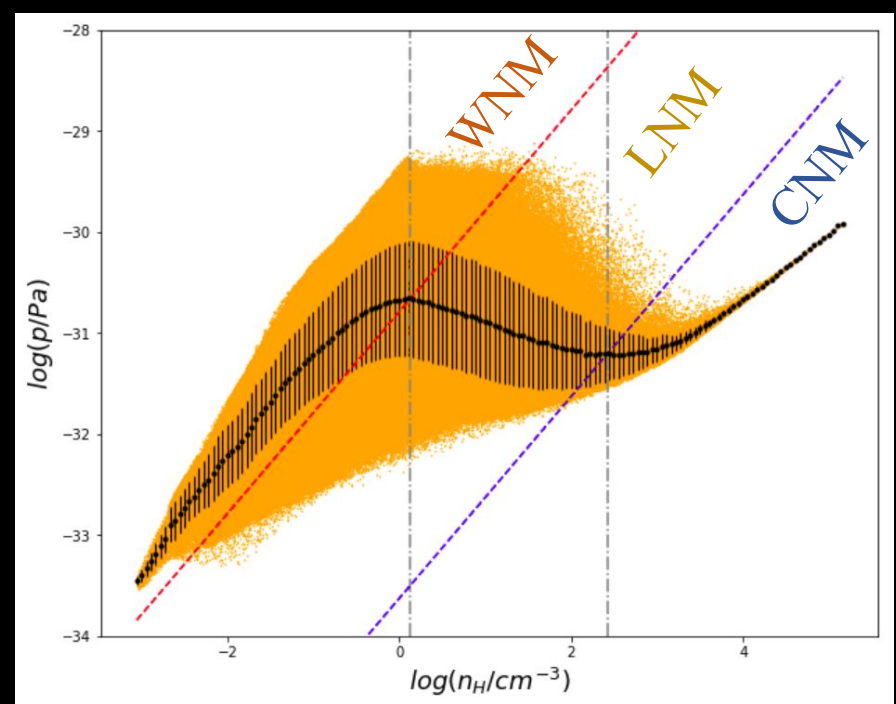


[Izvor: E. Saury et al., 2014, A&A 567, A16]

Faze neutralne materije



[Izvor: E. Saury et al., 2014, A&A 567, A16]



[Iz simulacije Bellomi et al., 2020.]

Simulirana opažanja

- ❖ Prijenos zračenja
- ❖ $h\nu \ll kT$
- ❖ Rayleigh-Jeansov zakon

$$T_b = T (1 - e^{-\tau_{\nu r}})$$

- ❖ Definicija optičke dubine
- ❖ $h\nu \ll kT$
- ❖ Lokalna termodinamička ravnoteža

$$\tau_{\nu r} = 5.49 \cdot 10^{-14} \frac{\text{Kcm}^3}{\text{s}} \int \frac{n_{\text{H}} P(\nu)}{T} dz$$

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$$T_b = 5.49 \cdot 10^{-14} \frac{\text{Kcm}^3}{\text{s}} \int n_{\text{H}} \frac{e^{-\frac{(v_{\text{lsr}} - v_z)^2}{b^2}}}{\sqrt{\pi} b} dz \quad \tau_{\nu r} \ll 1$$

$$b = \sqrt{\frac{2kT}{m}}$$

Simulirana opažanja

$$T_b^{\text{mjer}} = B(x, y) * T_b(v_{\text{lsr}}, x, y)$$

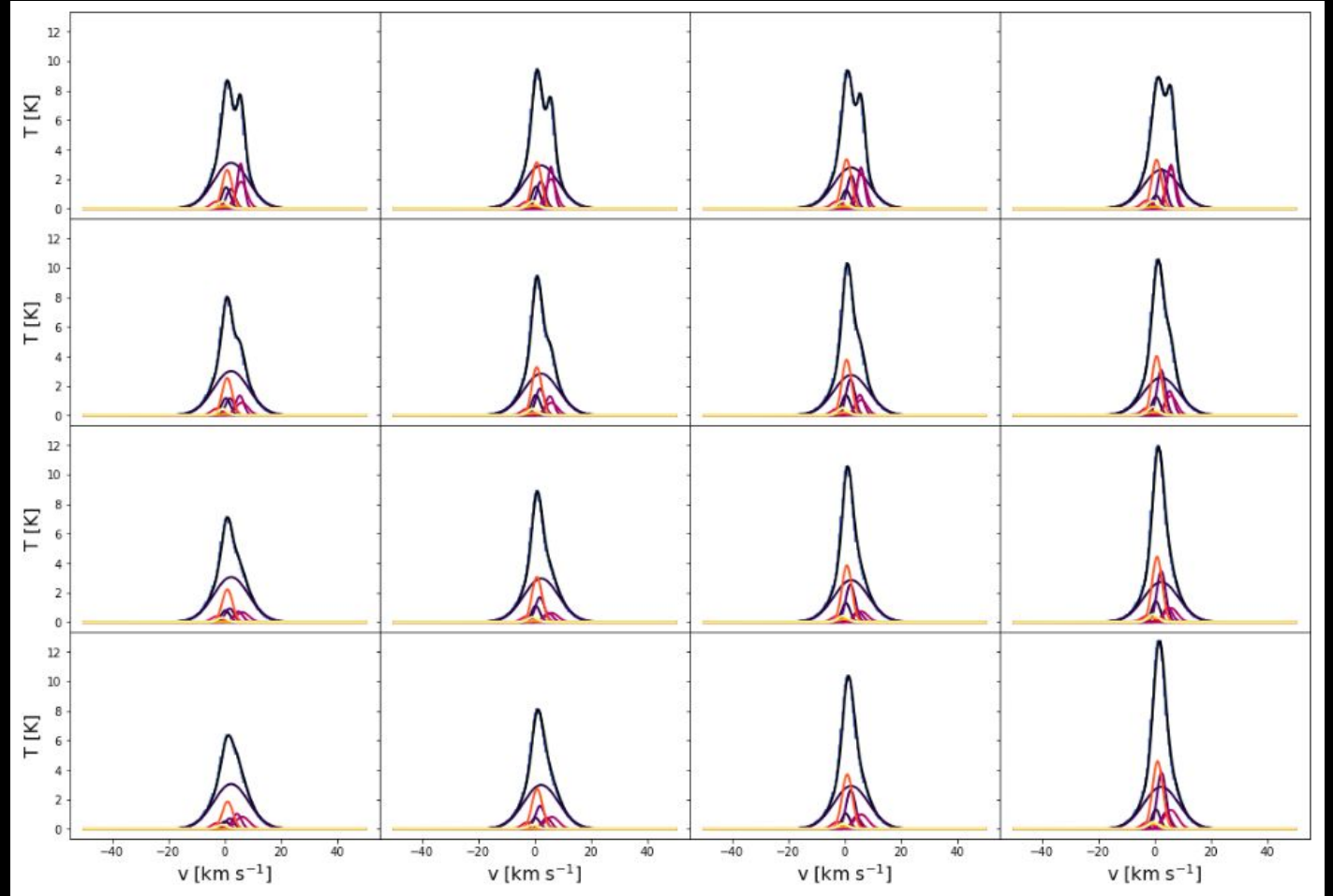
$$b'(x, y, z) = \sqrt{\frac{kT(x, y, z)}{m} + \sigma_{\text{psf}}^2}$$

❖ $v_{\text{lsr}} = [-50 \text{ km/s}, 50 \text{ km/s}]$

ROHSA

[A. Marchal et al., 2019, A&A 626, A101]

- ❖ Rastav faza iz opažanja
 - ❖ Rastav spektra na Gaussijane
 - ❖ Faze se odvajaju granicama u standardnoj devijaciji



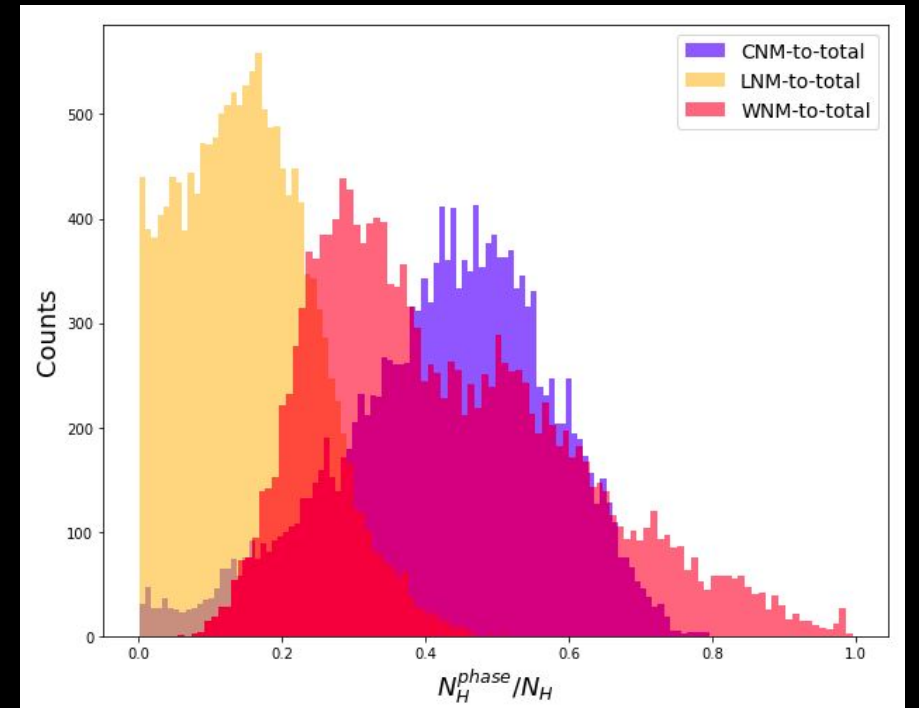
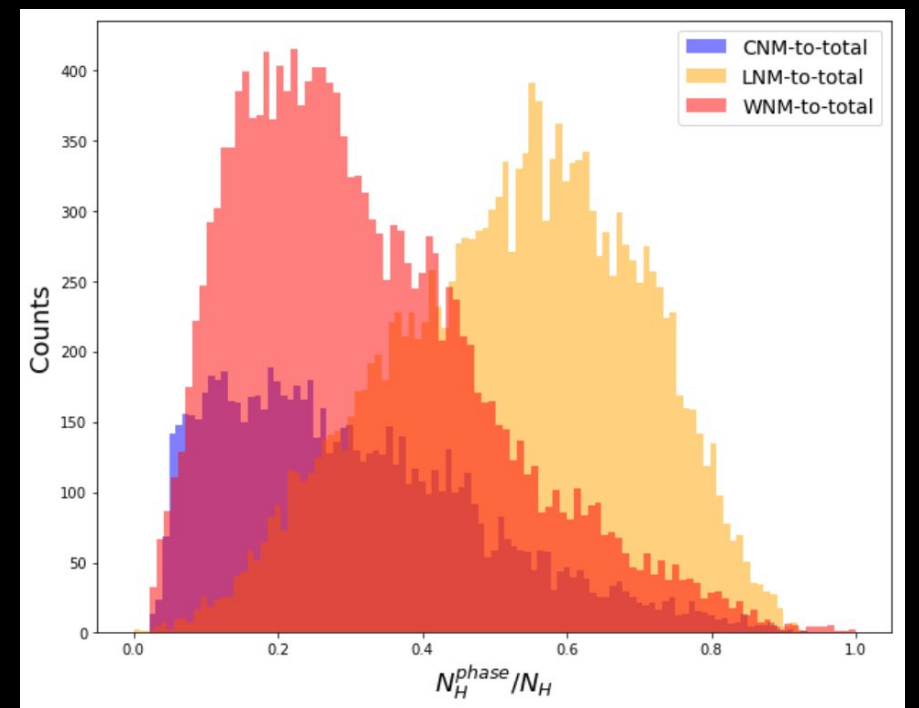
Rezultati

❖ Iz tlaka i temperature:

$$N_{\text{H}} = \int n_{\text{H}} dz$$

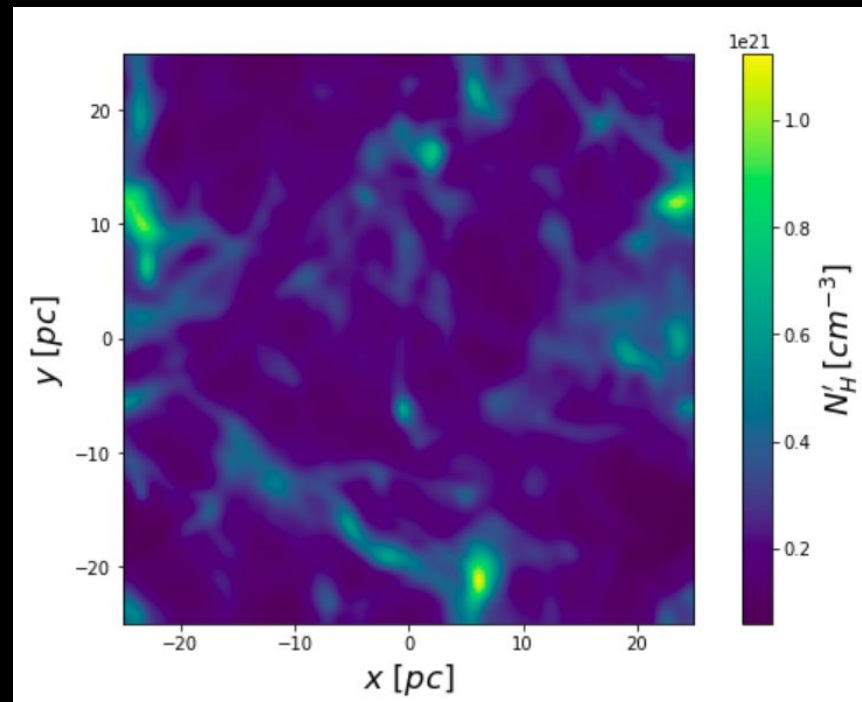
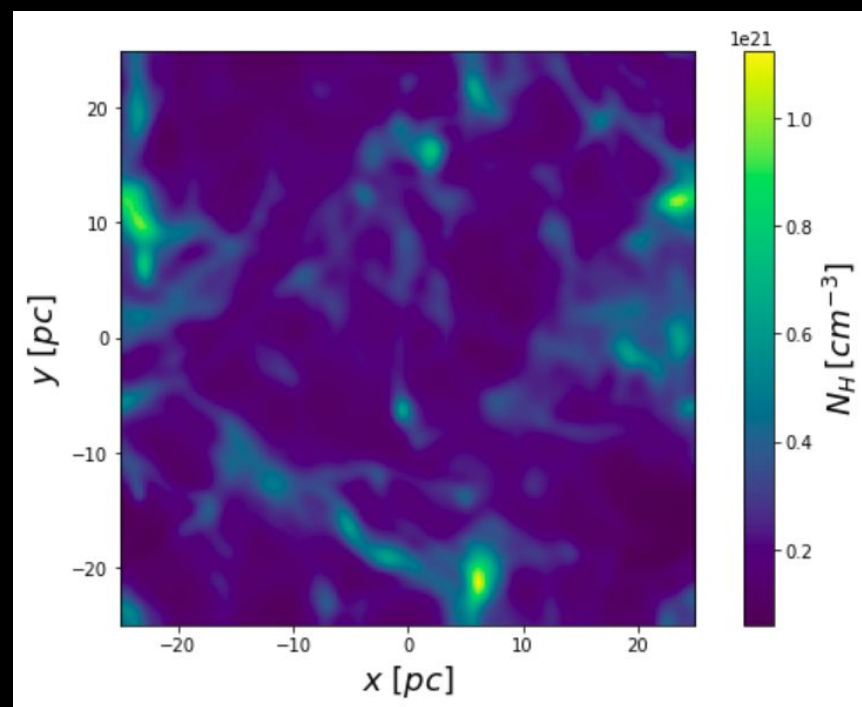
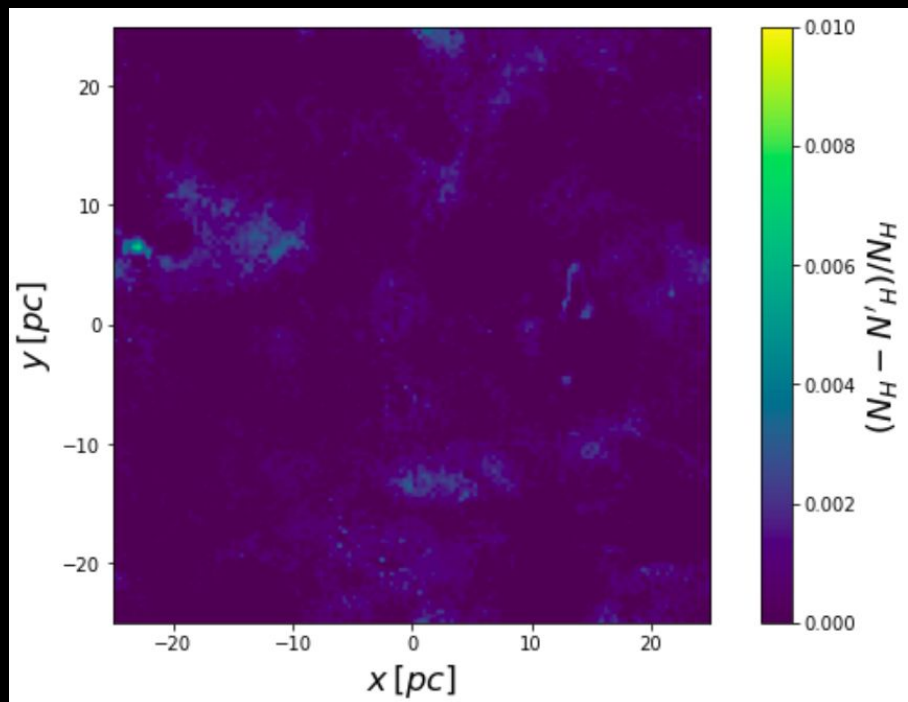
❖ Iz temperature sjaja i ROHSA paketa:

$$N_{\text{H}} = 1.823 \cdot 10^{13} \frac{\text{s}}{\text{Kcm}^3} \int T_{\text{b}} dv_{\text{lsr}}$$



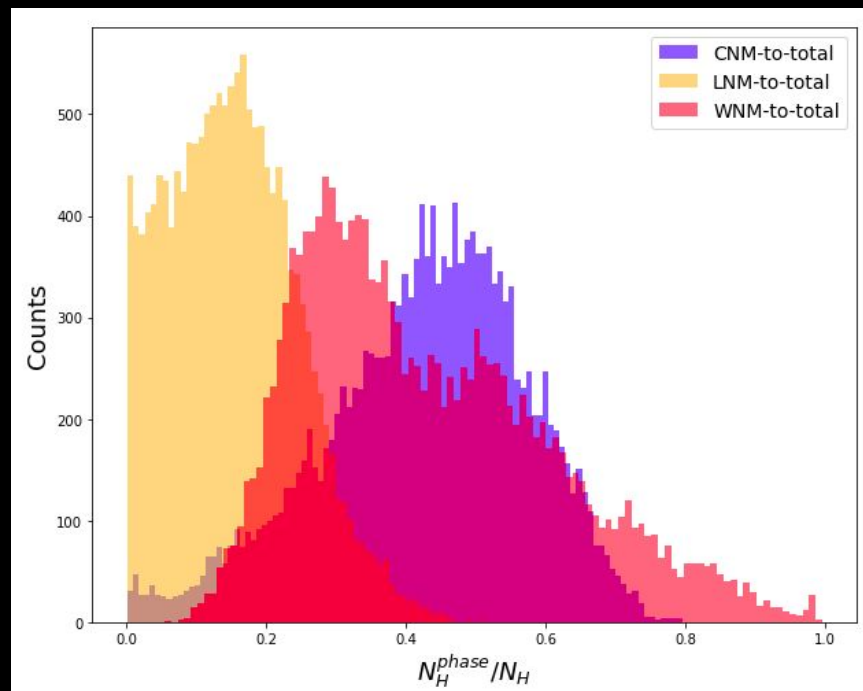
Rezultati

❖ Res $\approx 1\%$

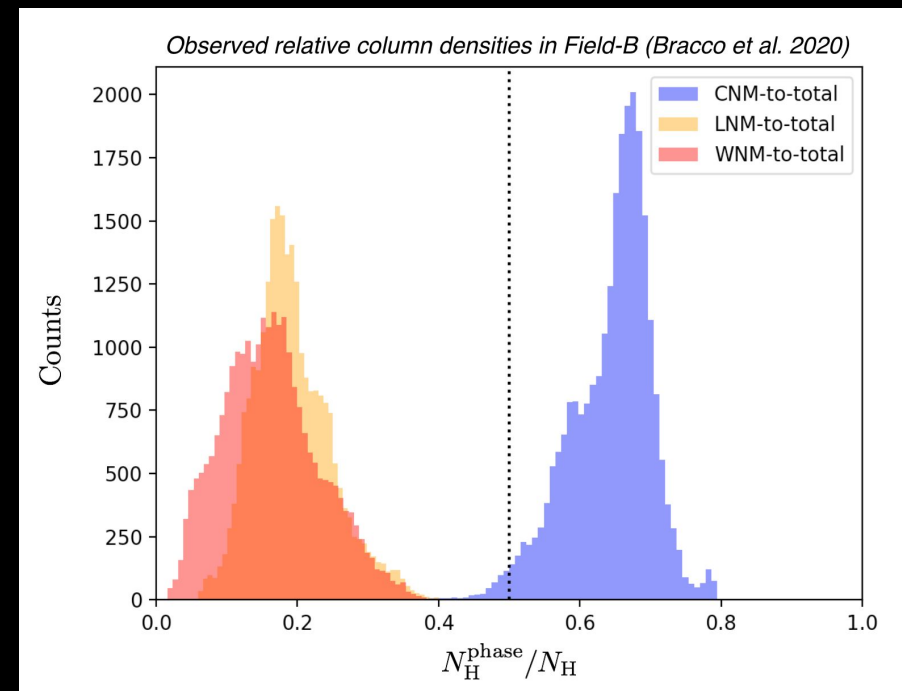


Rezultati

Simulacije iz Bellomi et al.:



EBHIS promatranja:



Zaključak

- ❖ Python kod za izračun temperature sjaja dostupan na GitHub-u
 - ❖ <https://github.com/BarbaraSiljeg/Brightness-temperature-of-21-cm-line-from-a-simulation>
- ❖ Analiza podataka možda povećava udio hladne faze neutralne materije
- ❖ Umjetno je povećani udio hladne faze mogući uzrok pronađene jake korelacije hladne faze i ionizirane materije
- ❖ Potrebna je daljnja analiza za donošenje čvrstih zaključaka

Hvala na pozornosti!

