# Put od difuznog atomskog gasa do formiranja zvezda: otvoreni problemi

*Snežana Stanimirović +*
*Claire Murray, Elijah Bernstein-Cooper, Bob Lindner, Brian Babler, Al Lawrence (University of Wisconsin, Madison)*



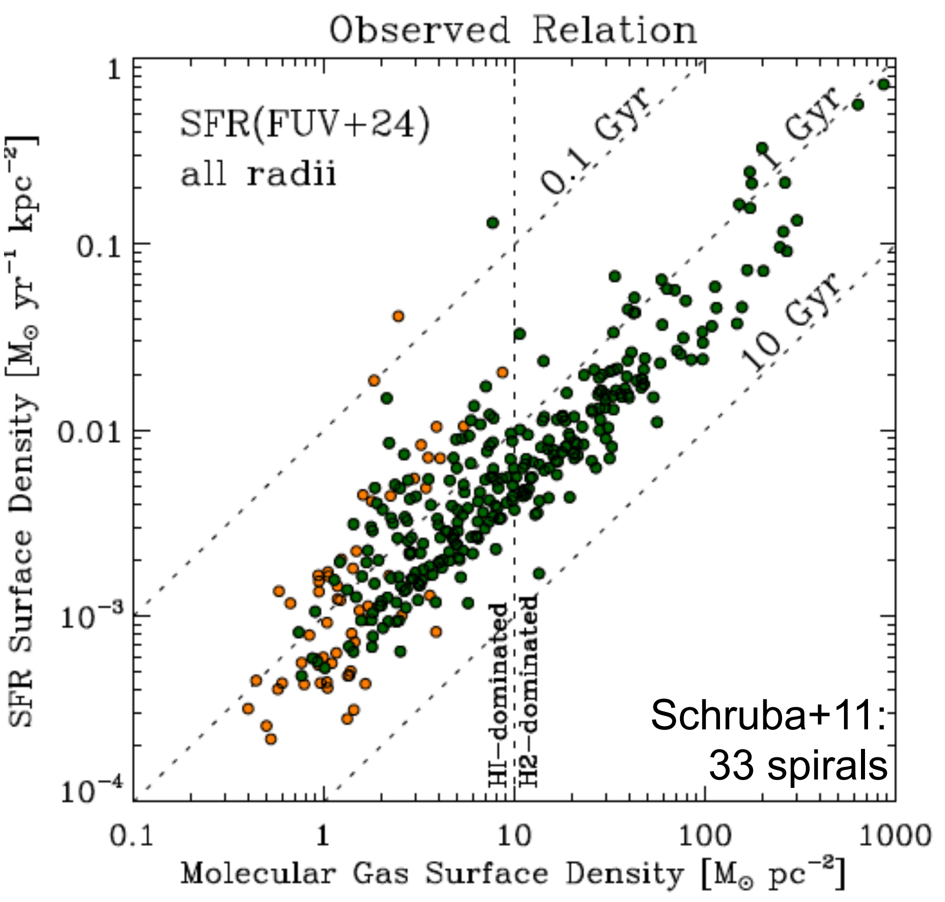

NSF

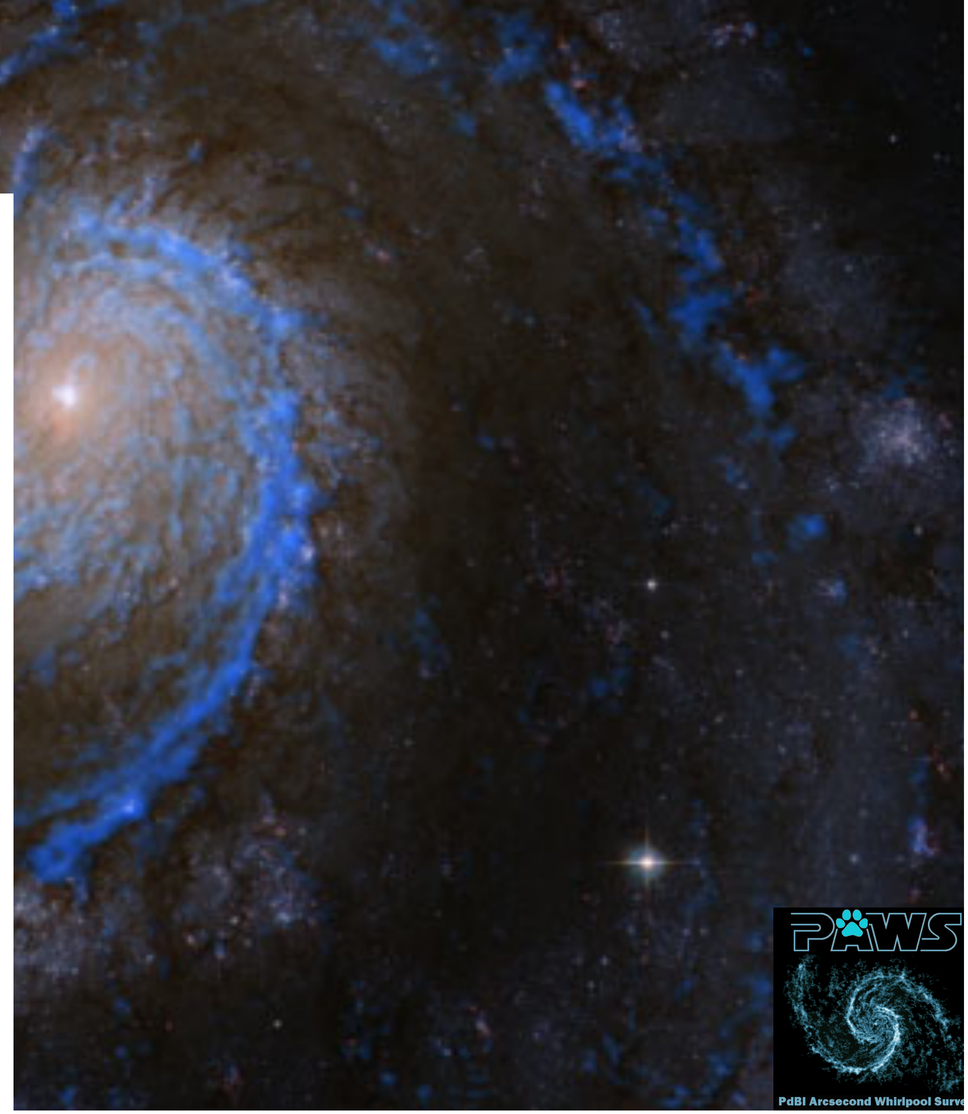
THE UNIVERSITY of WISCONSIN MADISON

RESEARCH CORPORATION for SCIENCE ADVANCEMENT
A foundation dedicated to science since 1912.

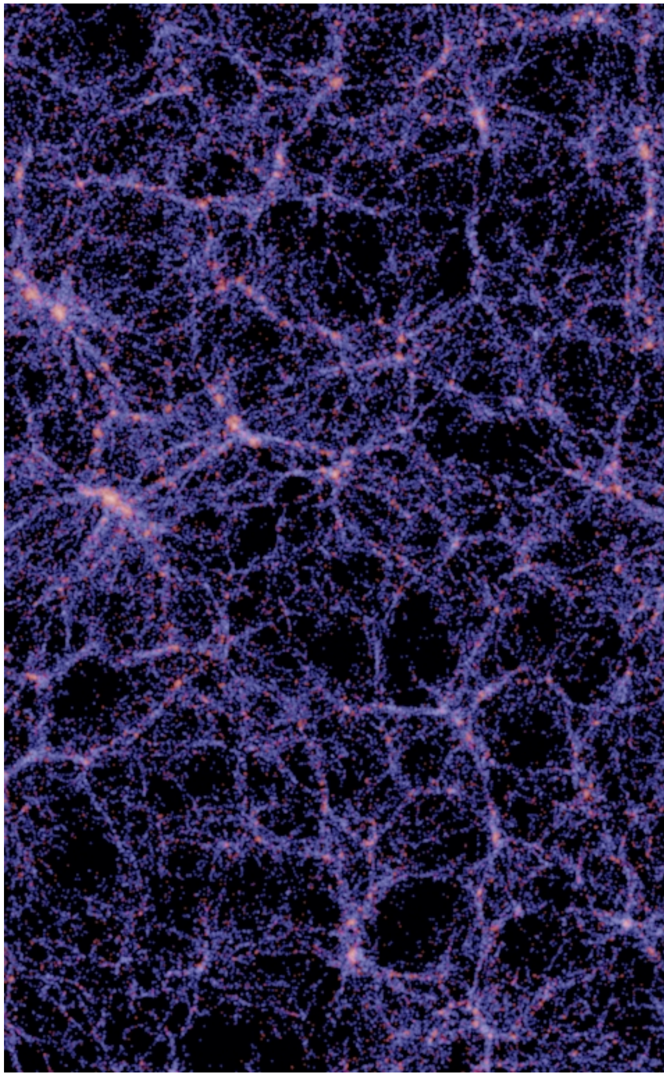
# Zvezde nastaju u oblacima molekularnog gasa

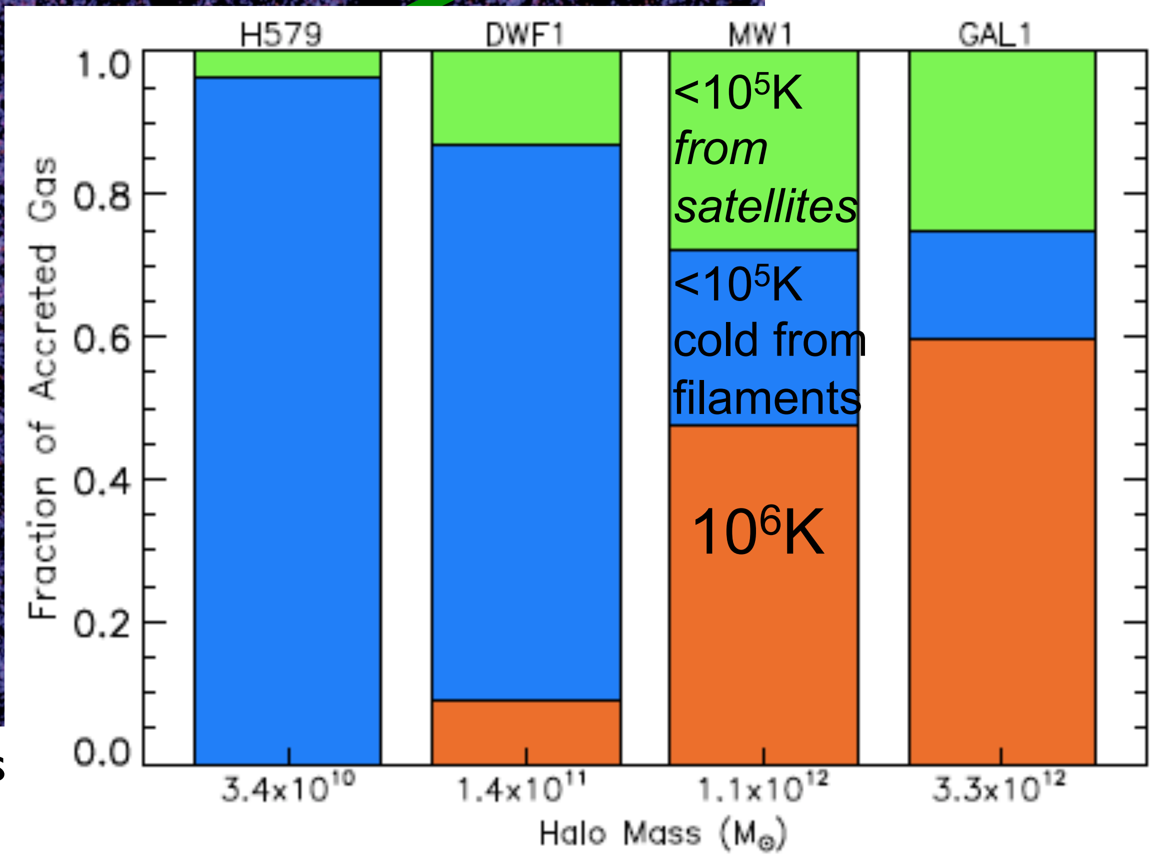
$\Sigma_{SFR} \sim \Sigma_{H2}$ : Efektivnost formiranja molekularnih oblaka je kljucna stvar za evoluciju galaksija.



# Galaksije u preseku kosmicki filamenata + accretion of matter






Brooks et al.09; Keres+09

“Millennium cosmological s
Springel+05

# Star formation cycle:

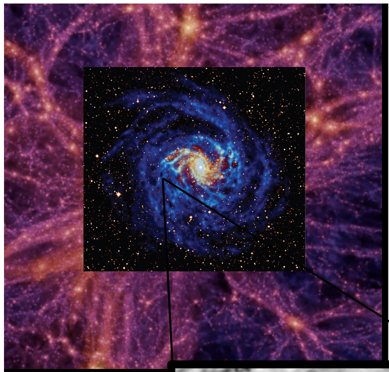
1. Kosmicki filamenti → galaksije?

*Magelanov Tok kao primer*

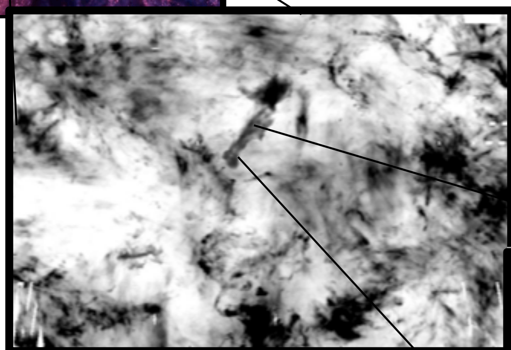
2. Difuzni ISM → formiranje oblaka

*Karakteristike difuznog ISM-a; Stepen turbulencije; Procesi formiranja oblaka*

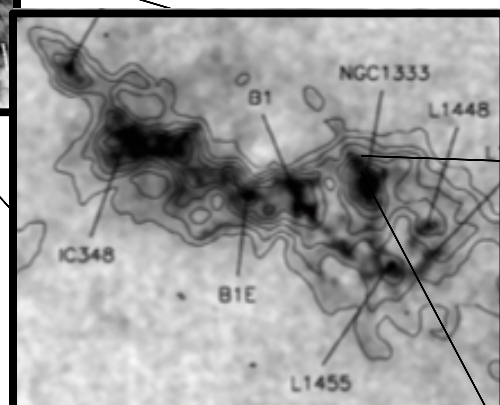
1.



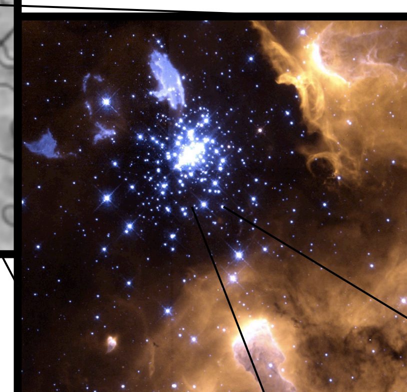
2.



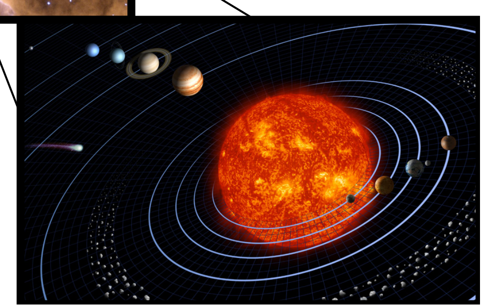
3.




4.



5.



3. Atomski → molecularni?

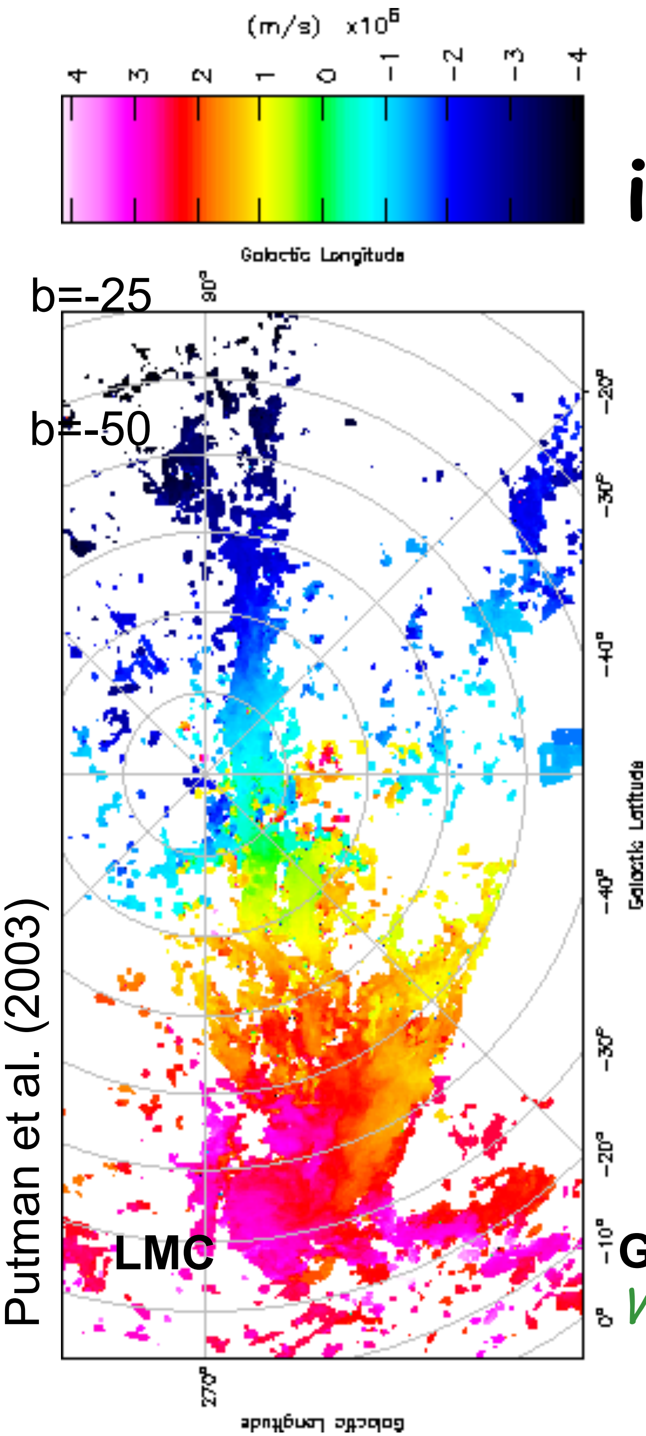
*Koliko je vazna zastita molekula?*

4. Molecularni oblaci → zvezde & planete

5. Zvezde → difuzni gas (*feedback*)

# Magelanov Tok: interakcija izmedju accretion materijala i Galakticke atmosfere

Putman et al. (2003)

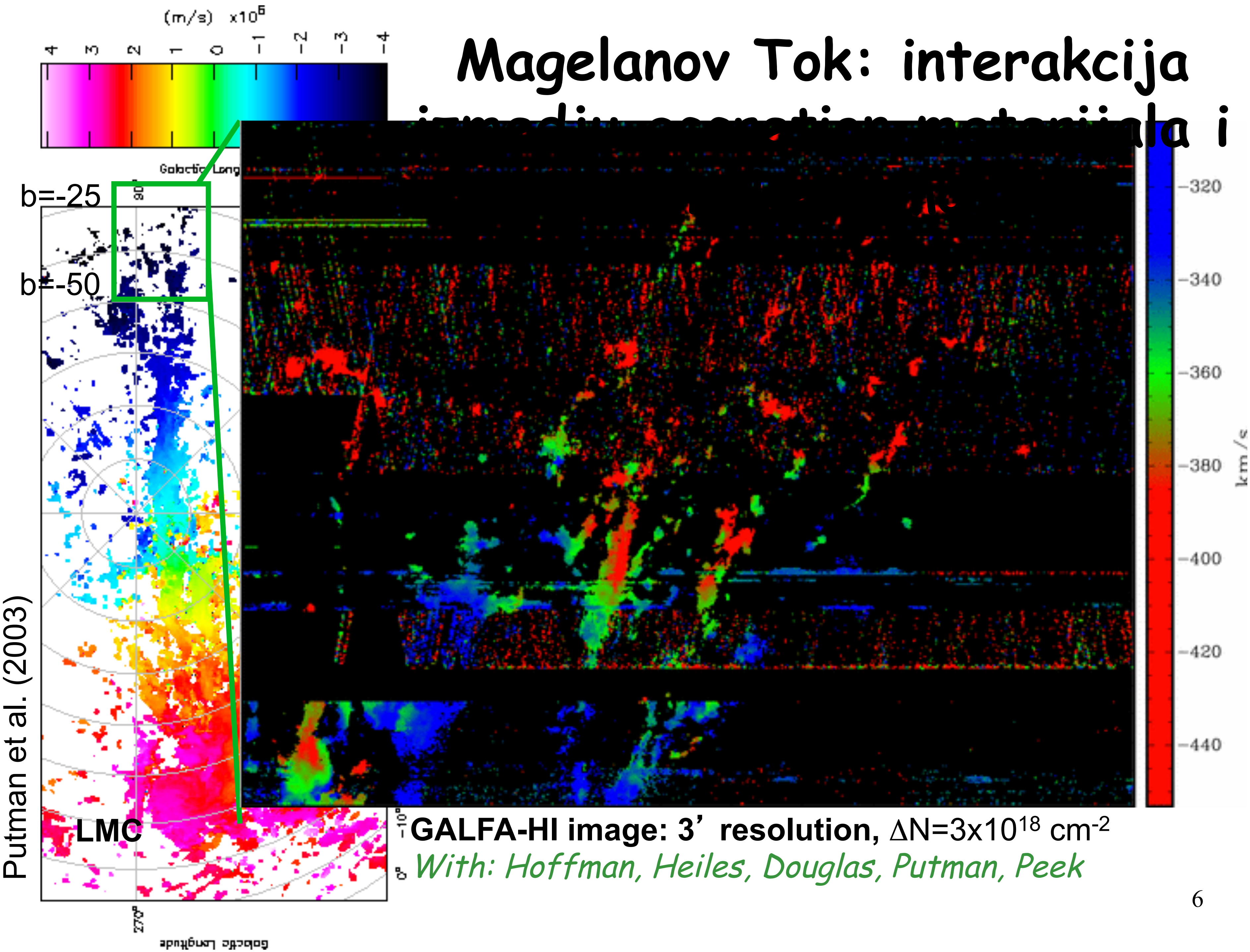



- Najblizi primer filamenta na prilazu galaksiji.
- Koliko materijala će stići do diska?

**GALFA-HI image: 3' resolution,** $\Delta N = 3\times10^{18}$ cm$^{-2}$

*With: Hoffman, Heiles, Douglas, Putman, Peek*

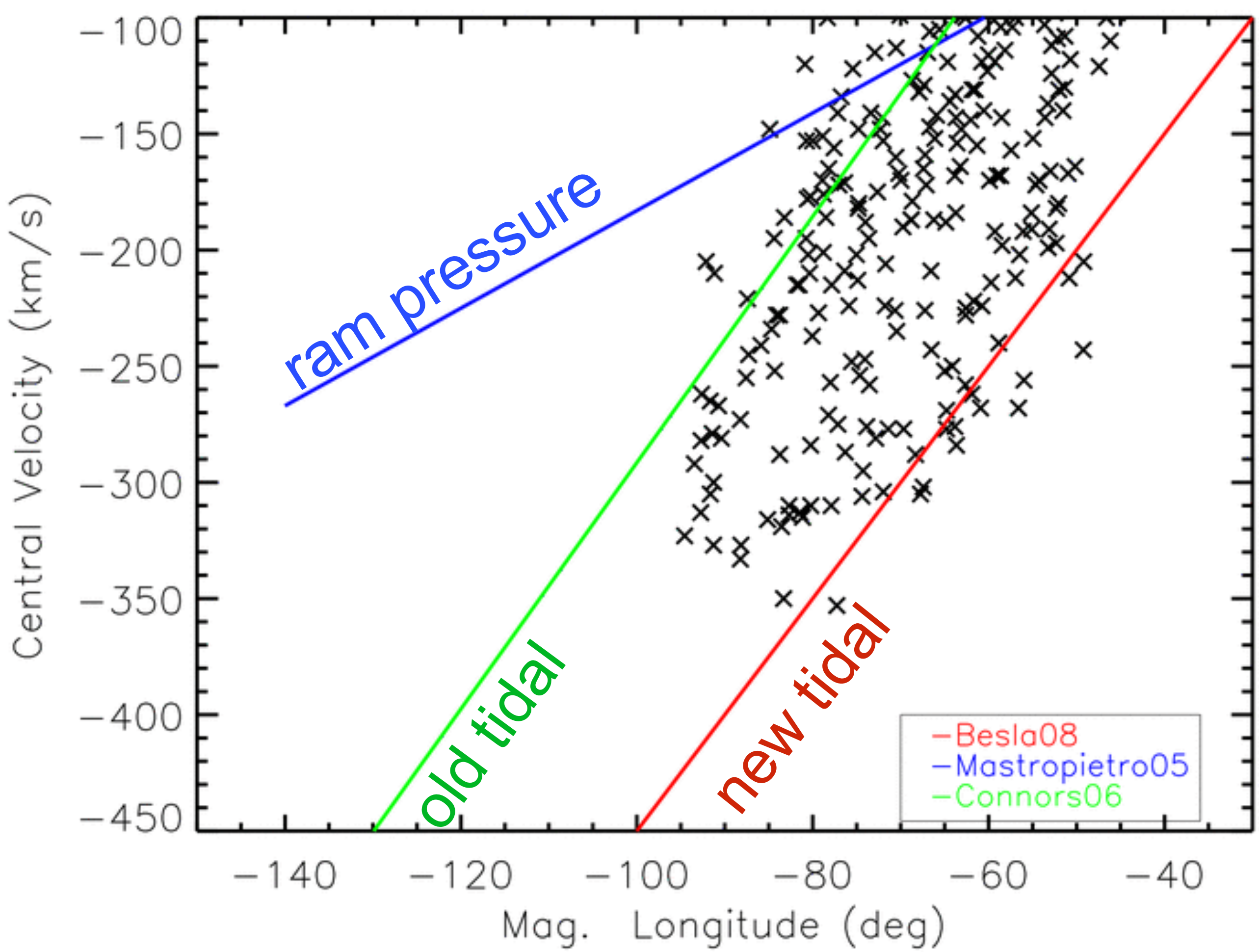
# Magelanov Tok: interakcija




**GALFA-HI image: 3' resolution,** $\Delta N = 3 \times 10^{18}\ cm^{-2}$

*With: Hoffman, Heiles, Douglas, Putman, Peek*

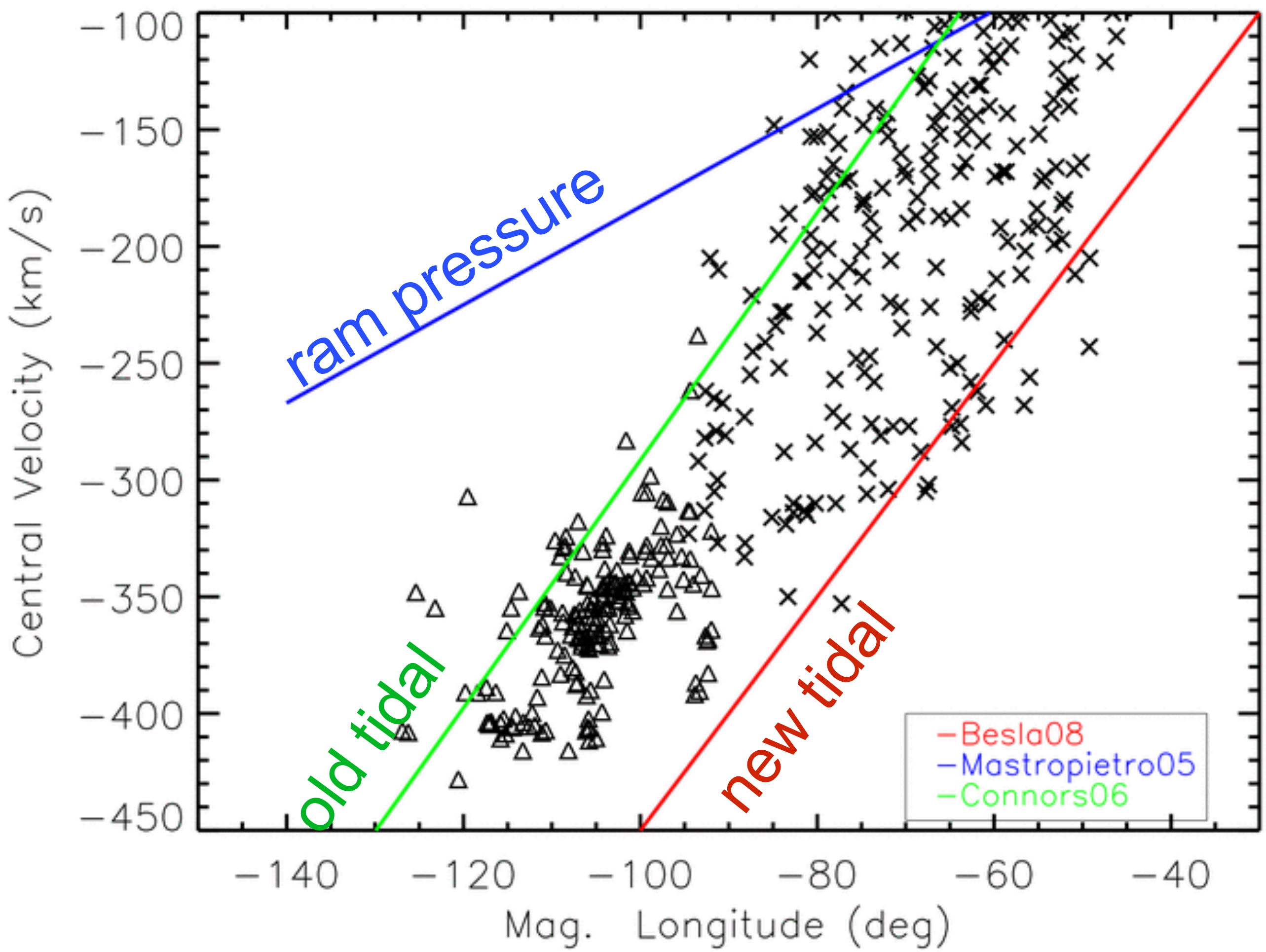
# Arecibo posmatranja i gradijent brzine




↑ LMC

X Putman03

# Arecibo posmatranja i gradijent brzine



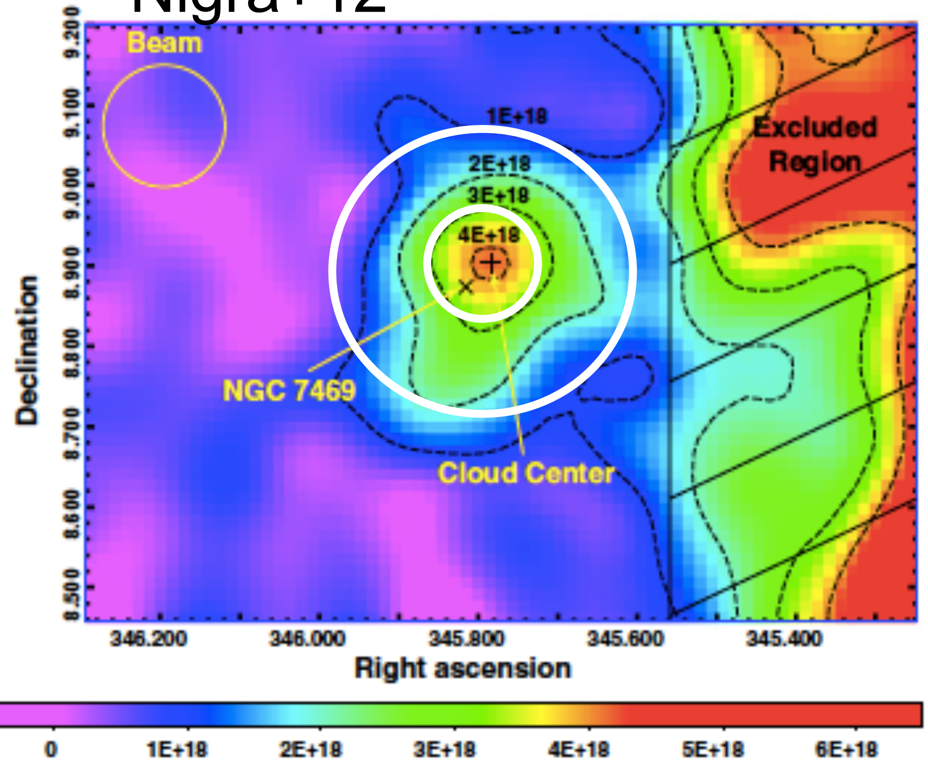

↑ LMC

X Putman03
∆ GALFA

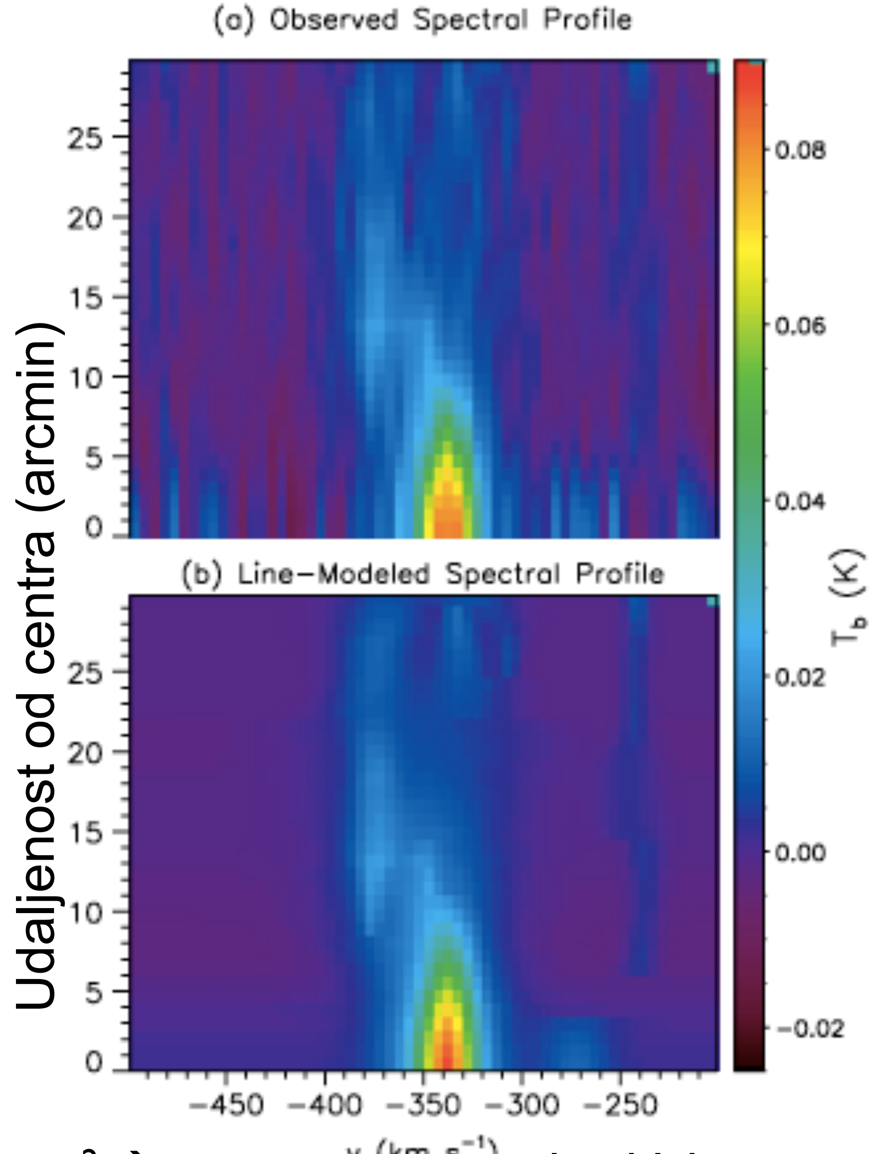
Stanimirovic, Gallagher, Nigra 2003, SAJ

# Jezgro i omotač HI oblaka

Nigra+12




(a) Column Density (color scale in $cm^{-2}$)





Omotač: N(HI) = $2 \times 10^{18}$ $cm^{-2}$ → veca mogucnost da oblak stigne do diska MW-a

# Star formation cycle:

1. Kosmicki filamenti → galaksije?
*Magelanov Tok kao primer*

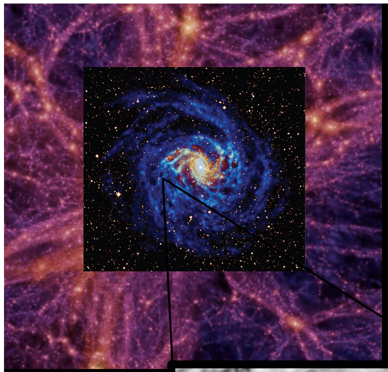
2. Difuzni ISM → formiranje oblaka
*Karakteristike difuznog ISM-a; Stepen turbulencije; Procesi formiranja oblaka*

3. Atomski → molecularni?
*Koliko je vazna zastita molekula?*

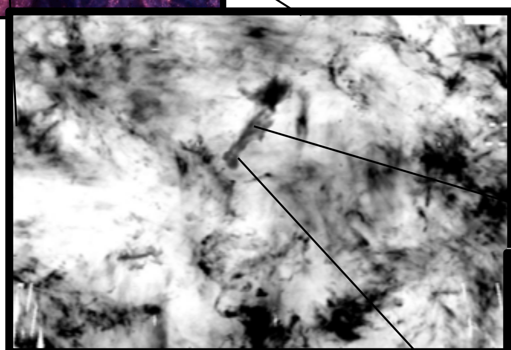
4. Molecularni oblaci → zvezde & planete
*Najmanji difuzni oblaci (AU-scale) u ISM-u?*

5. Zvezde → difuzni gas (*feedback*)

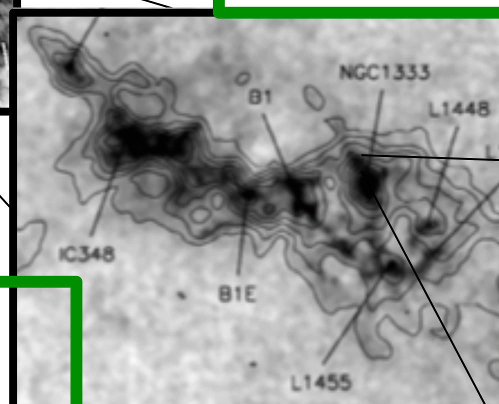
1.



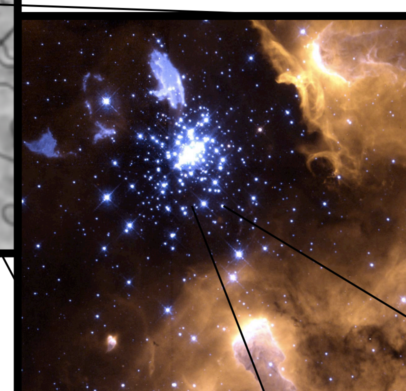
2.



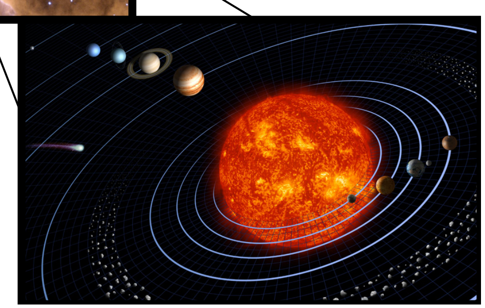
3.




4.



5.

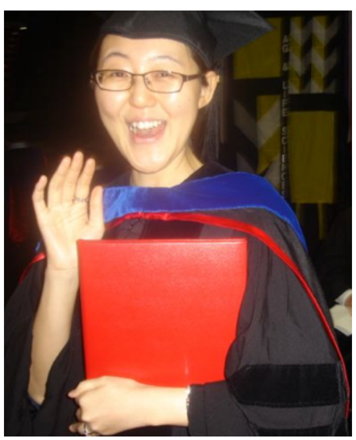


# Sadrzaj:

1. Fizicki uslovi za formiranje molekularnih oblaka
→21-SPONGE:

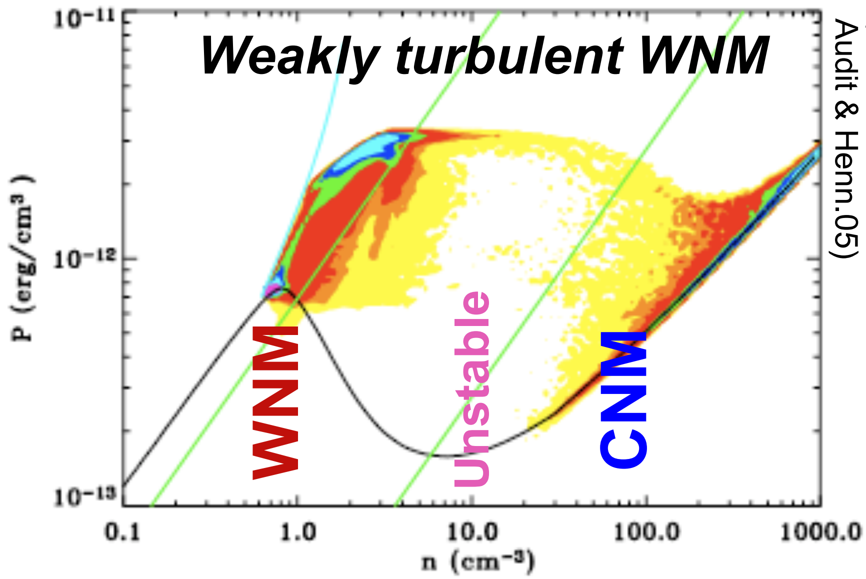
**Claire Murray**, **Bob Lindner**, M. Goss (NRAO), J. Dickey (UTas), C. Heiles (Berkeley), P. Hennebelle (CEA, Paris)
+ UW ugrads

2. HI-$H_2$ tranzicija i Xco u Perseus molekularnom oblaku:

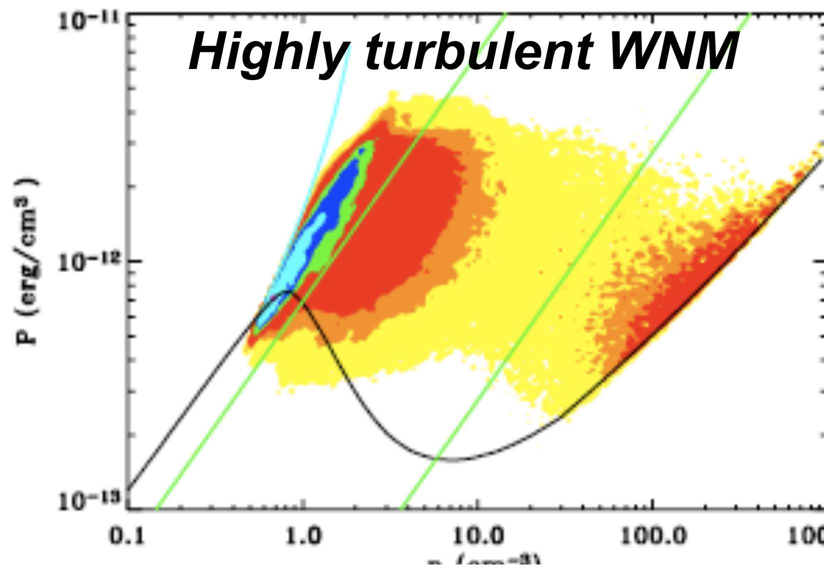


**Min-Young Lee**, K. Douglas, L. Knee, J. Di Francesco, S. Gibson, A. Begum, J. Grcevich, C. Heiles, E. Korpela, A. Leroy, J. Peek, N. Pingel, M. Putman, D. Saul, C. Murray, M. Wolfire, J. Miller, L. Knee, J. Di Francesco, A. Leroy, R. Shetty, S. Glover, F. Molina, R. Klessen

# Fizicki uslovi za formiranje hladnih oblaka (T, n)?




(McKee & Ostriker77;Wolfire03; Audit & Henn.05)




AH05, Mac Low+05, Hill+12, Clark+12

**Equilibrium Theory**: 2 stable phases.

P/k ~ 1700 - 4400 $cm^{-3}$ K

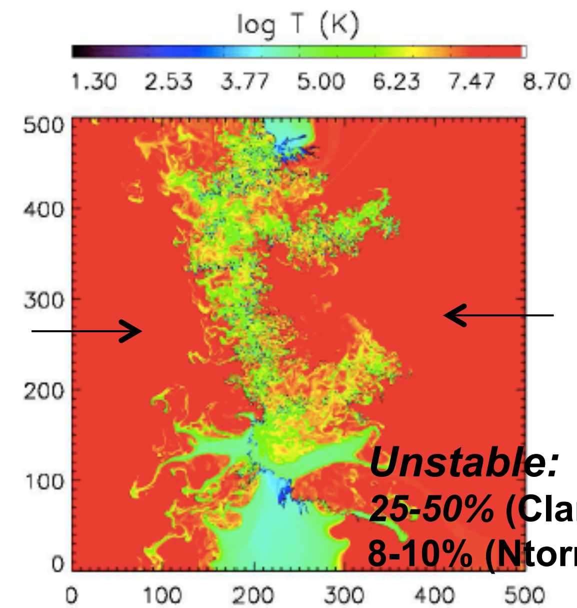
– **Warm Neutral Medium** :

Tk ~ 8000 K > Ts (Liszt01)

– **Cold Neutral Medium**:

Tk ~ 50 K = Ts

Posmatranja su neophodna da testiraju modele i simulacije.



# Hladjenje & zagrevanje HI regiona

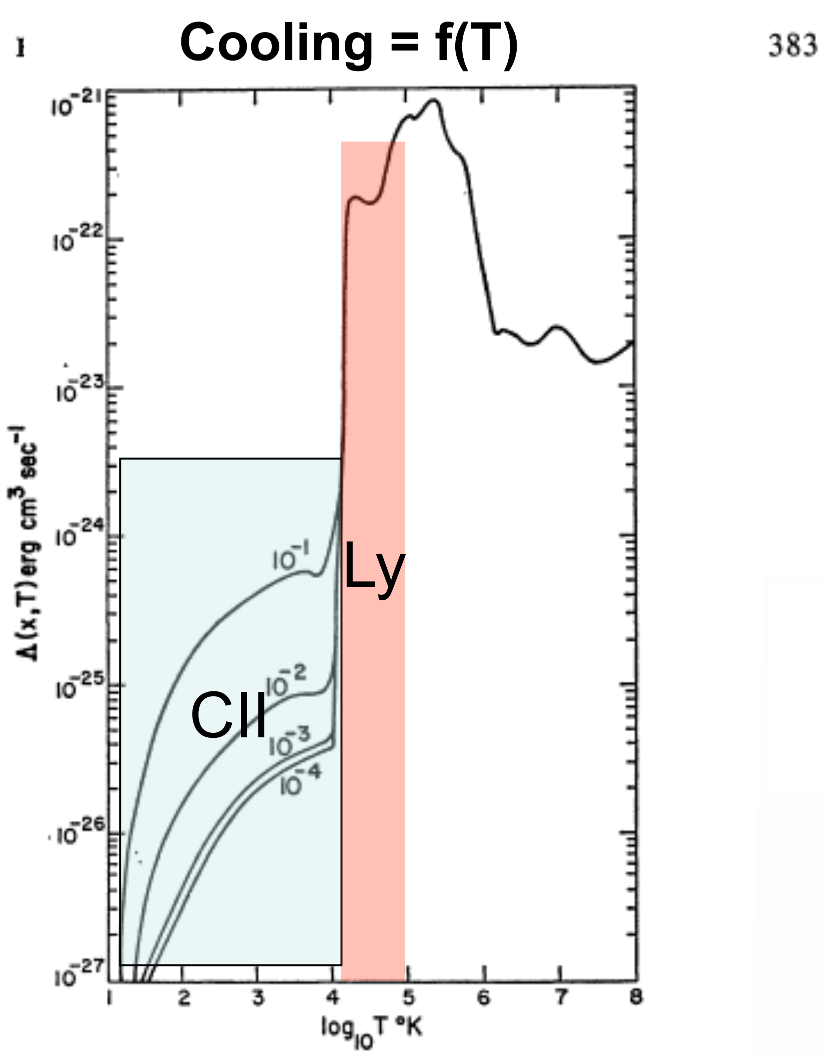
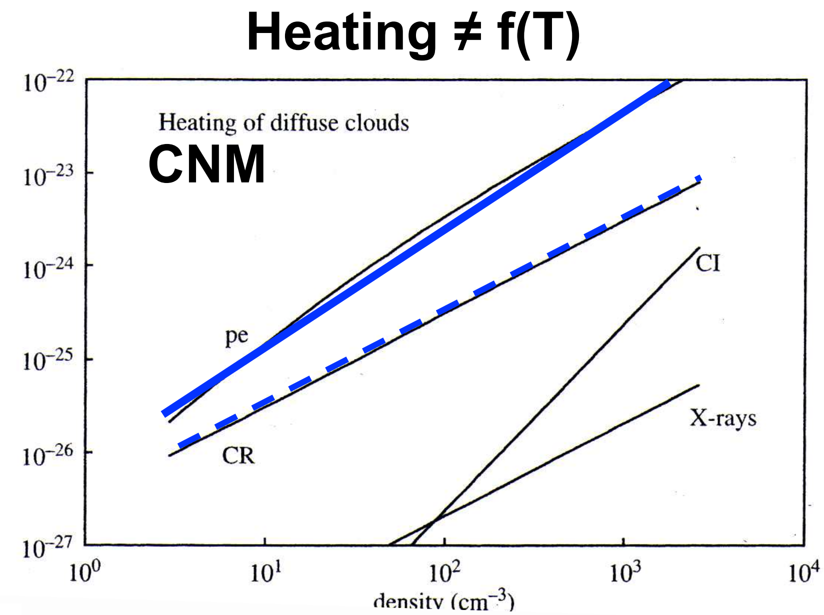
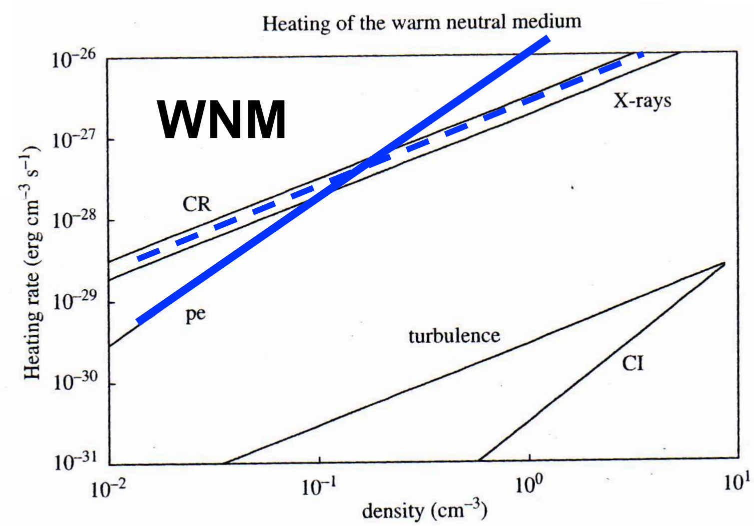


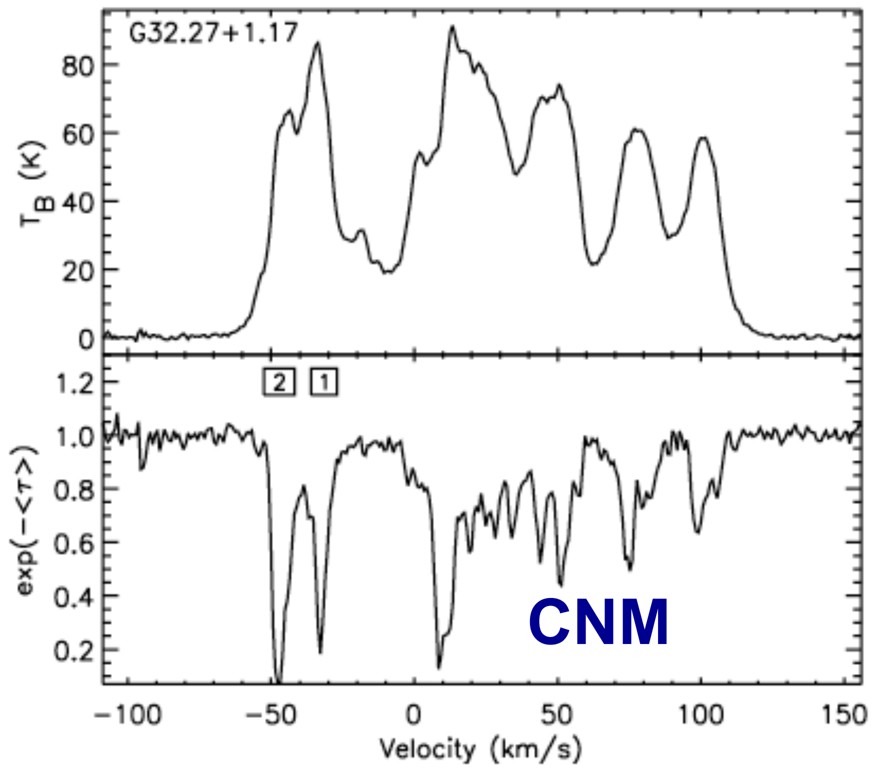

FIGURE 2. The interstellar cooling function $\Lambda(x, T)$ for various values of the frac ionization $x$. The labels refer to the values of $x$.

Tielens knjiga



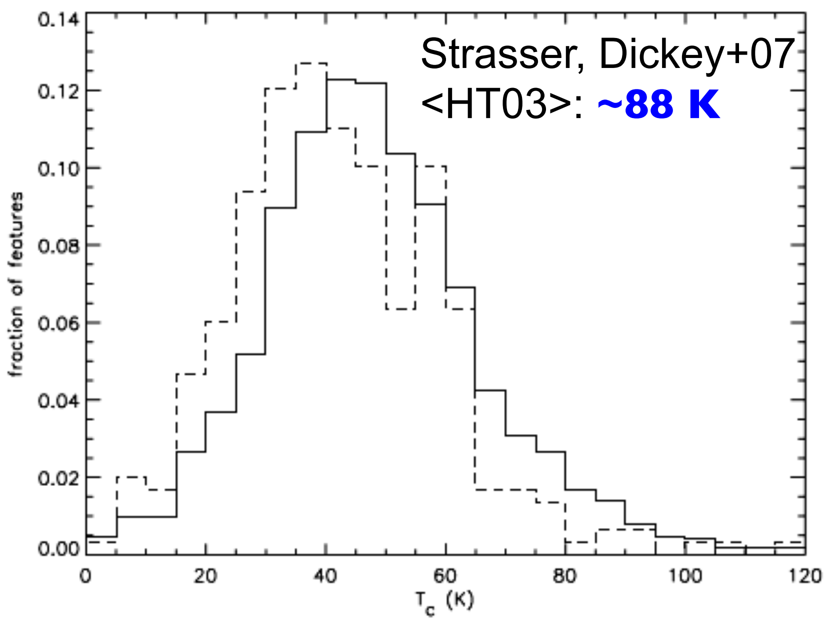



# CNM temperatura? Centralni vs periferni deo MW




Ts(CNM) se lako meri.

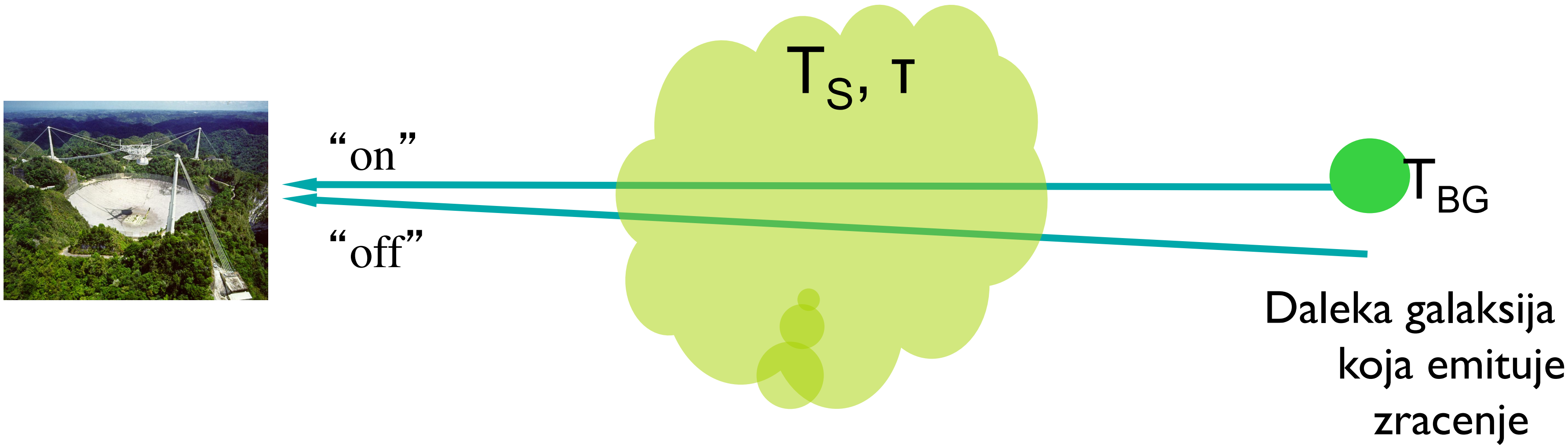
Problem: <Ts>, CNM fraction: (Inner MW) ~ (Outer MW) !




(VLA + Canadian + Southern) Galactic plane surveys

| | Inner Galaxy | Outer Galaxy |
|---|---|---|
| **<Ts>** | **48 +/- 10 K** | **38 +/- 10 K** |
| # per kpc | 0.03-1 | 0.02-0.08 |

# Merenje temperature medjuzvezdanih oblaka u Mlecnom putu




Jednacine prenosa zracenja kroz medjuzvezanu materiju

- Towards a bright source

$$\Delta T_B(\text{on}) = (T_S - T_{BG})(1 - e^{-\tau_\nu}) < 0$$

- Off source

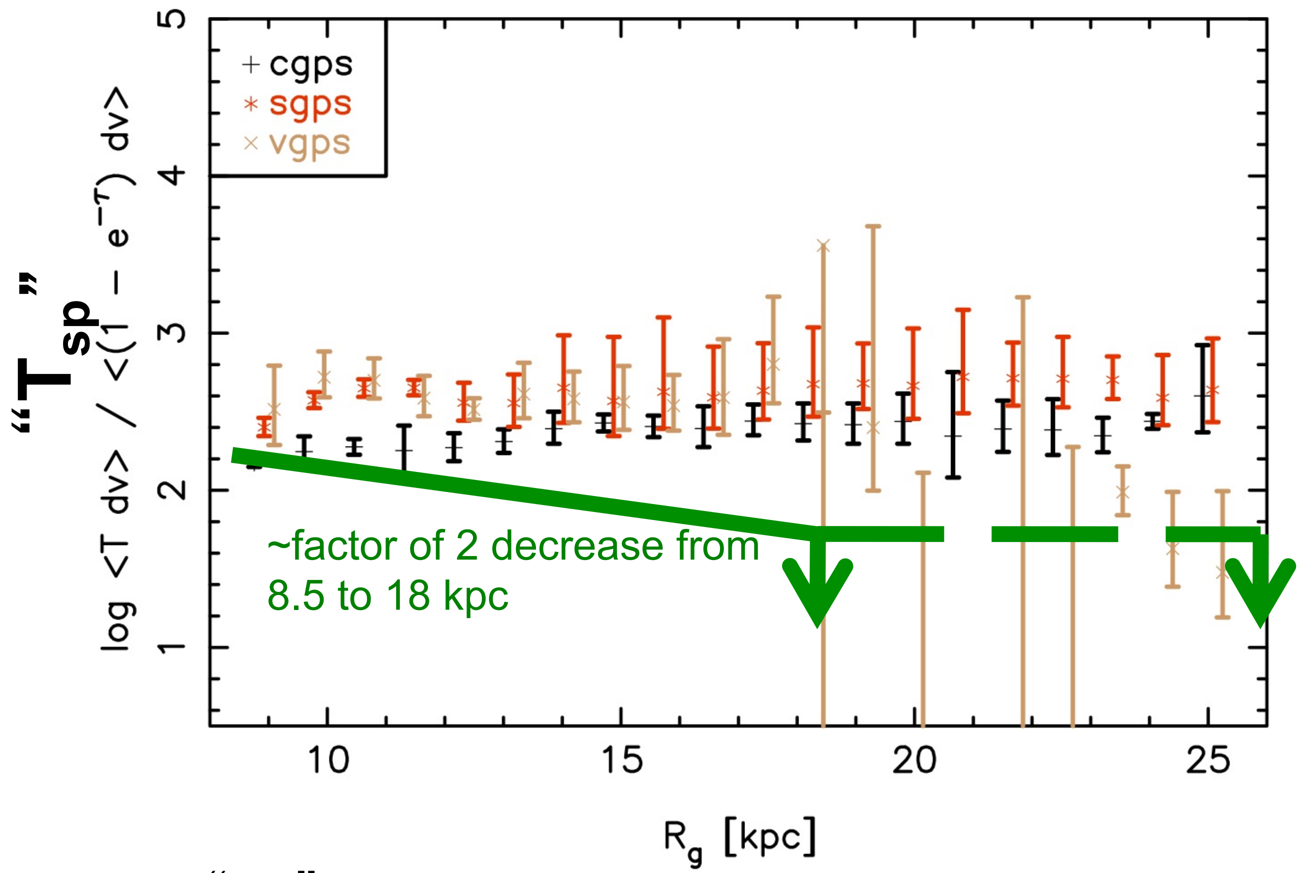
$$\Delta T_B(\text{off}) = T_S(1 - e^{-\tau_\nu}) > 0$$

assuming uniformity of $T_S$ and $\tau_\nu$

- Two unknowns, two equation solve for $T_S$ and $\tau_\nu$

→ Dobijamo temperaturu Ts i kolicinu apsorpcije (τ)

# Do li se $T_{sp}$ menja u zavisnosti od lokacije u disku?




Dickey et al. 09:
**290 spectra** from SGPS, CGPS, VGPS.
Integrated properties.

$$\langle T_{sp}\rangle = \frac{T_{EM}}{(1-e^{-\tau})} = \frac{\int n\, ds}{\int \frac{n}{T_{kin}}\, ds},$$

$$\langle T_{sp}\rangle = T_{cool}\,\frac{n_{WNM}+n_{CNM}}{n_{CNM}},$$

**---- Wolfire+03 model**

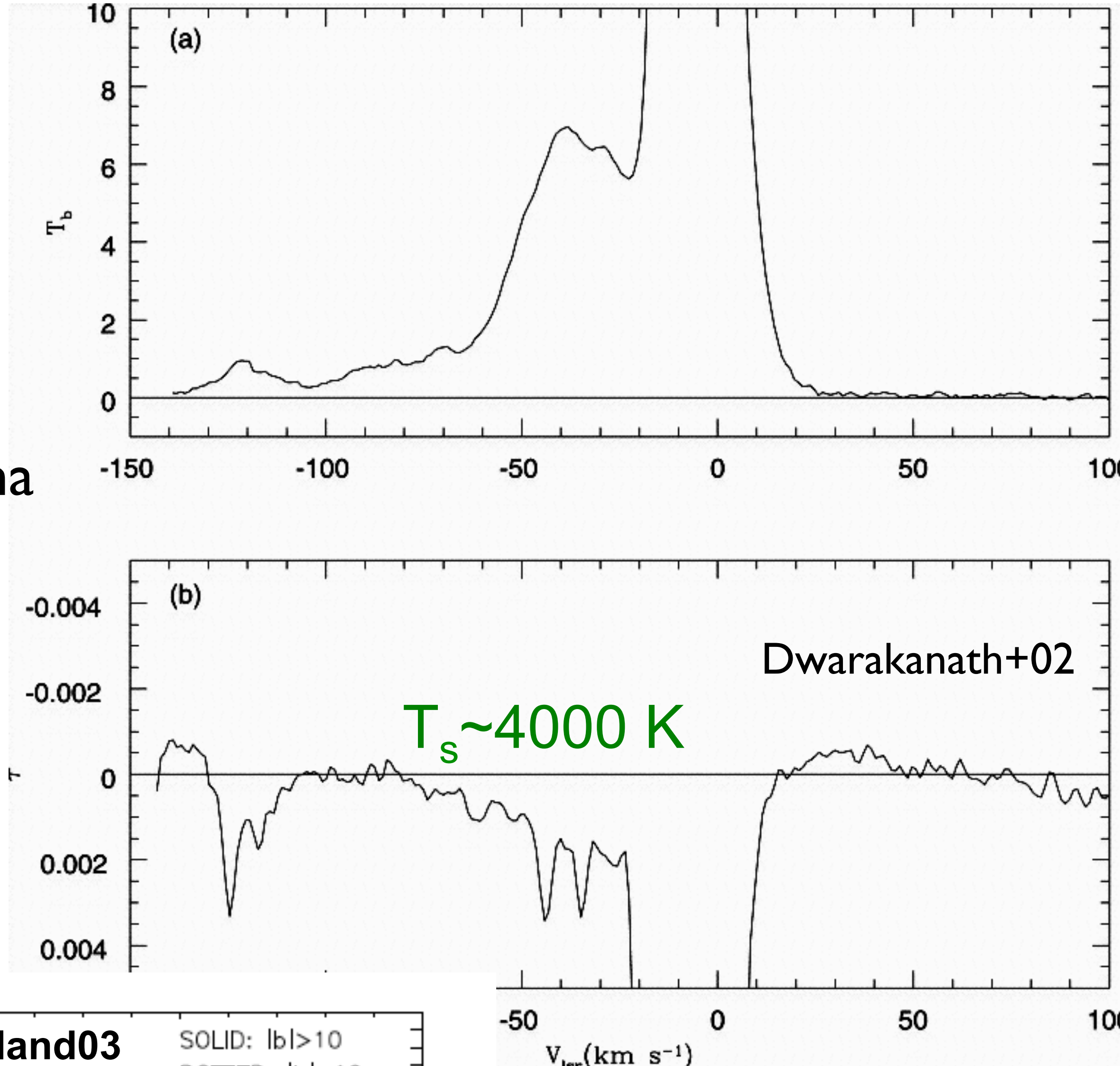
"$T_{sp}$"~300 K. Posmatranja: $T_{cool}$ ~ const.
→ CNM fraction ~ const. za R = $R_0$ to 3x$R_0$.

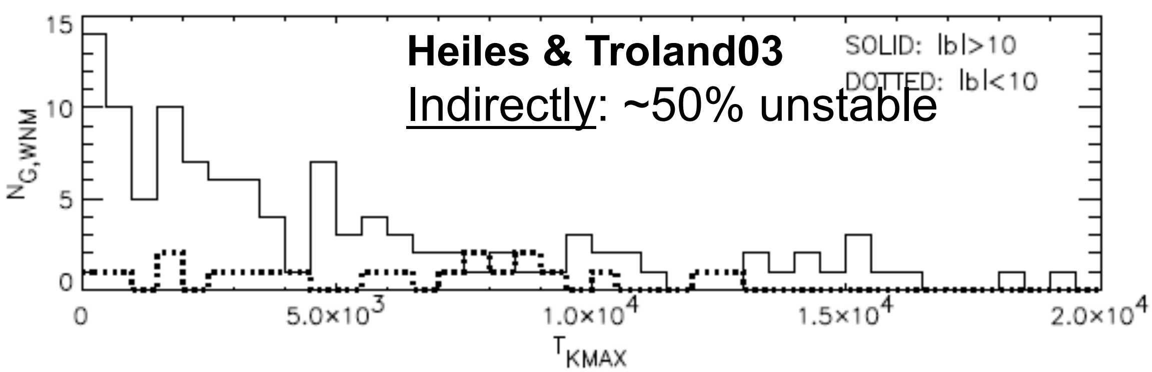
Neocekivano!

# Jako malo se zna o temperaturi WNM-a:

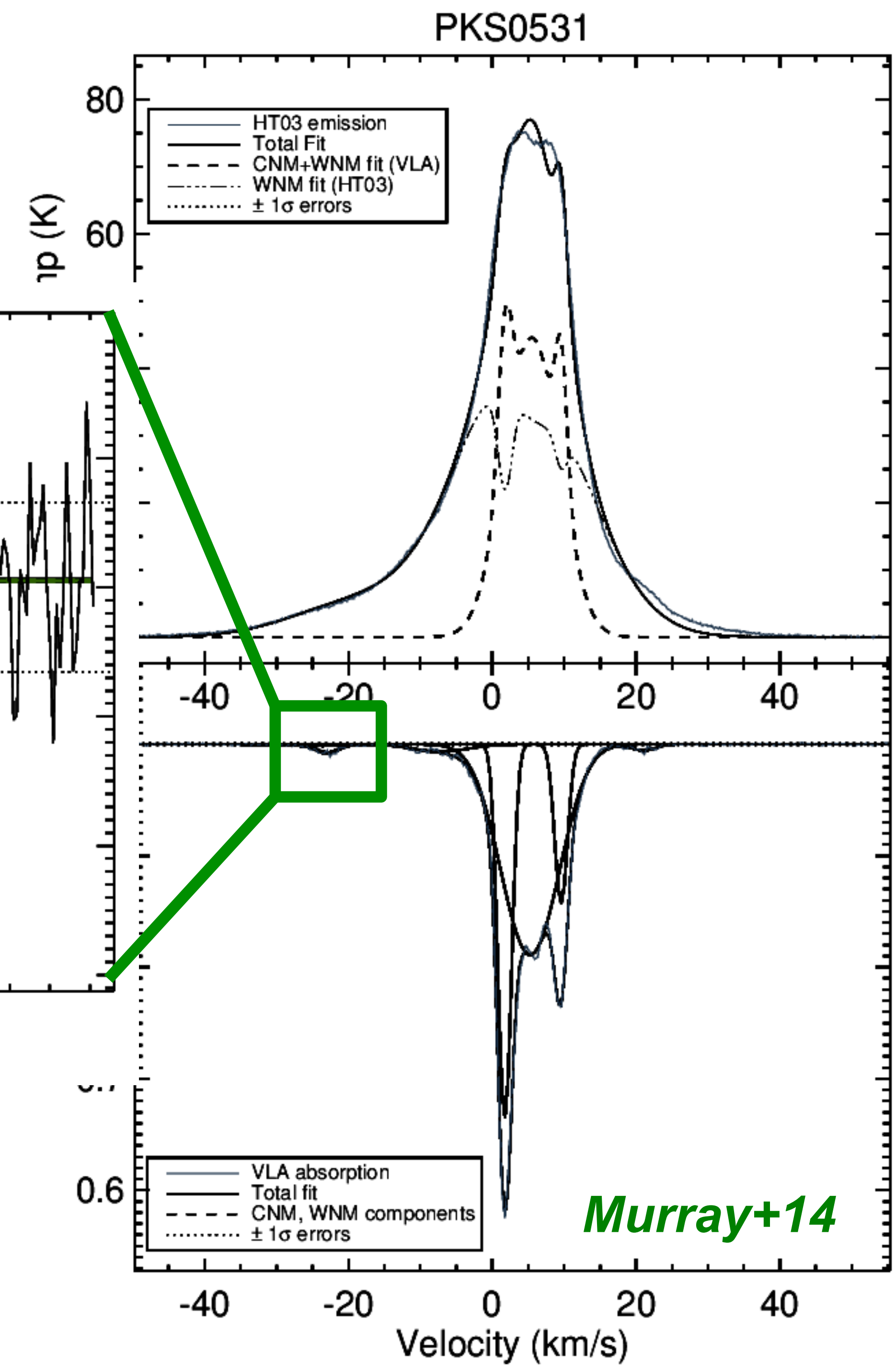
- Zahteva jako senzitivna posmatranja.

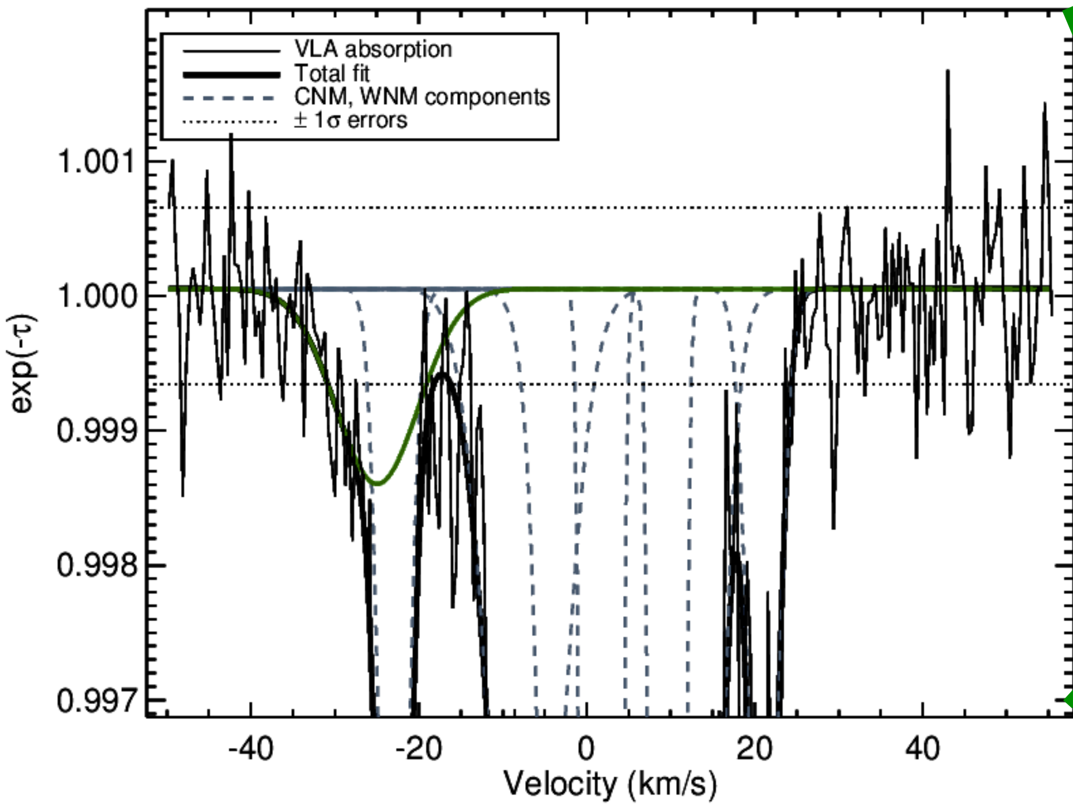
- Samo nekoliko direktnih posmatranja postoji.



# 21-SPONGE: 21cm Spectral line Observations of Neutral Gas with the

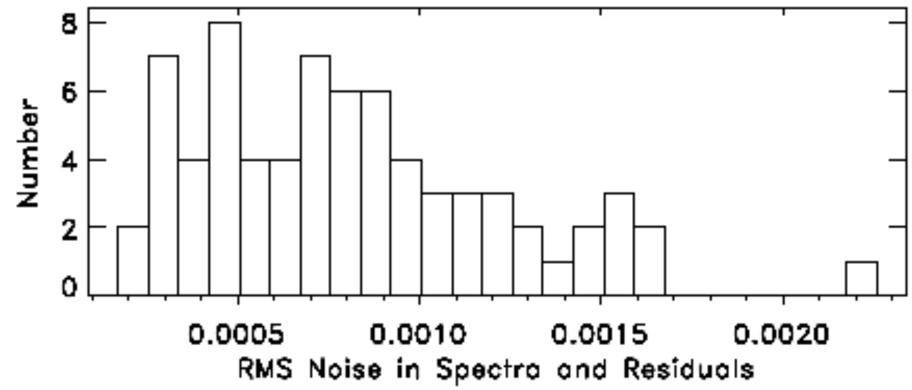


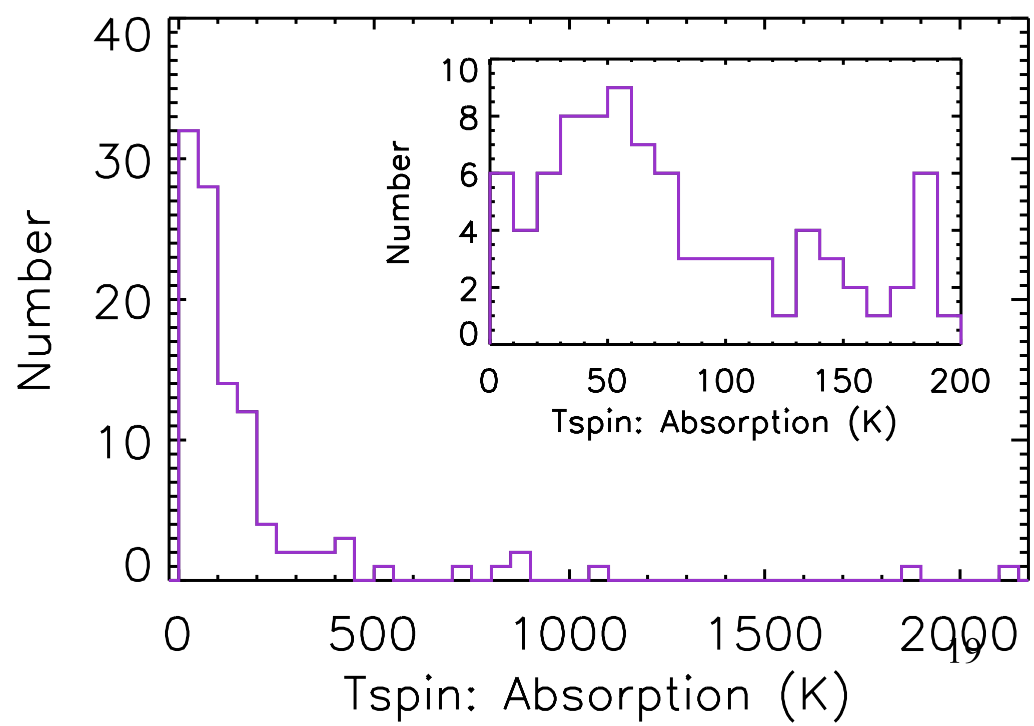


+


# 21-SPONGE (~24/60 objekata): jako mali broj direktnih WNM detekcija!

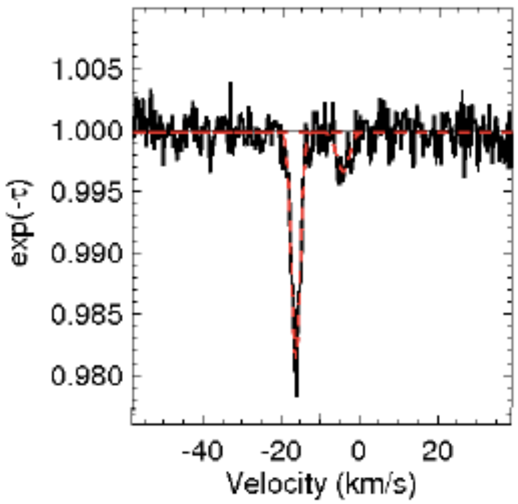



- Excellent sensitivity! $\Delta\tau \sim 5\text{x}10^{-4}$
- Most detections Ts<500 K → CNM.
- Tiny fraction (4%) of detections with Ts>1000 K (HT03 – 0%).
- Murray et al.



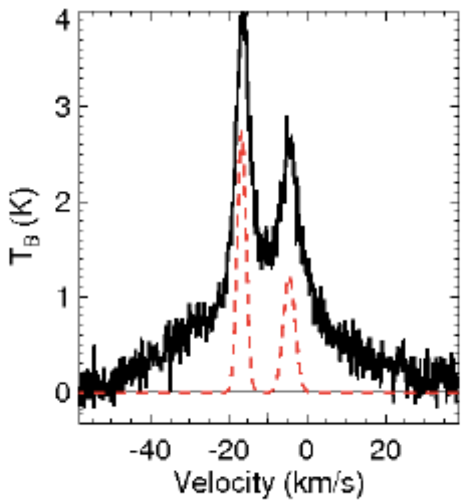
# Stacking Analysis Example

1. Fit absorption lines

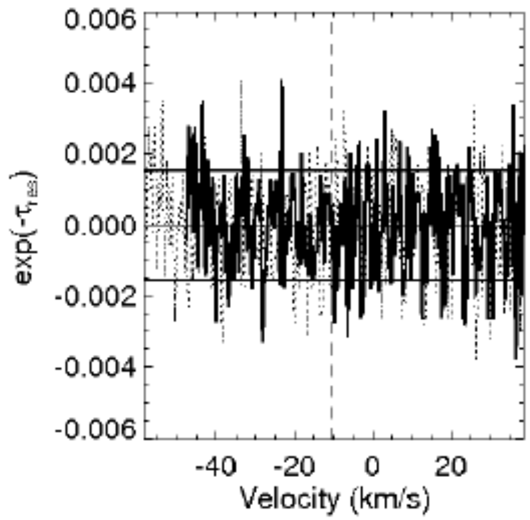


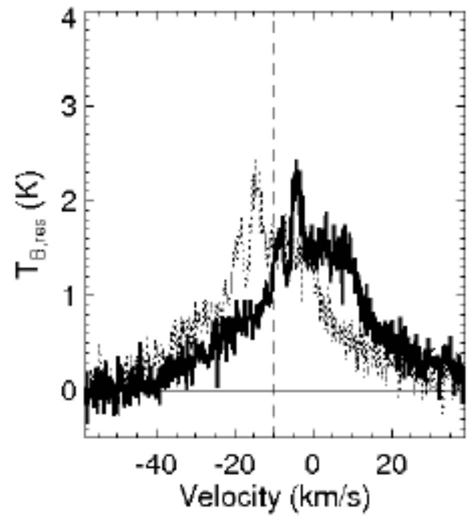

2. Solve for emission

$T_B = T_s(1-e^{-tau})$

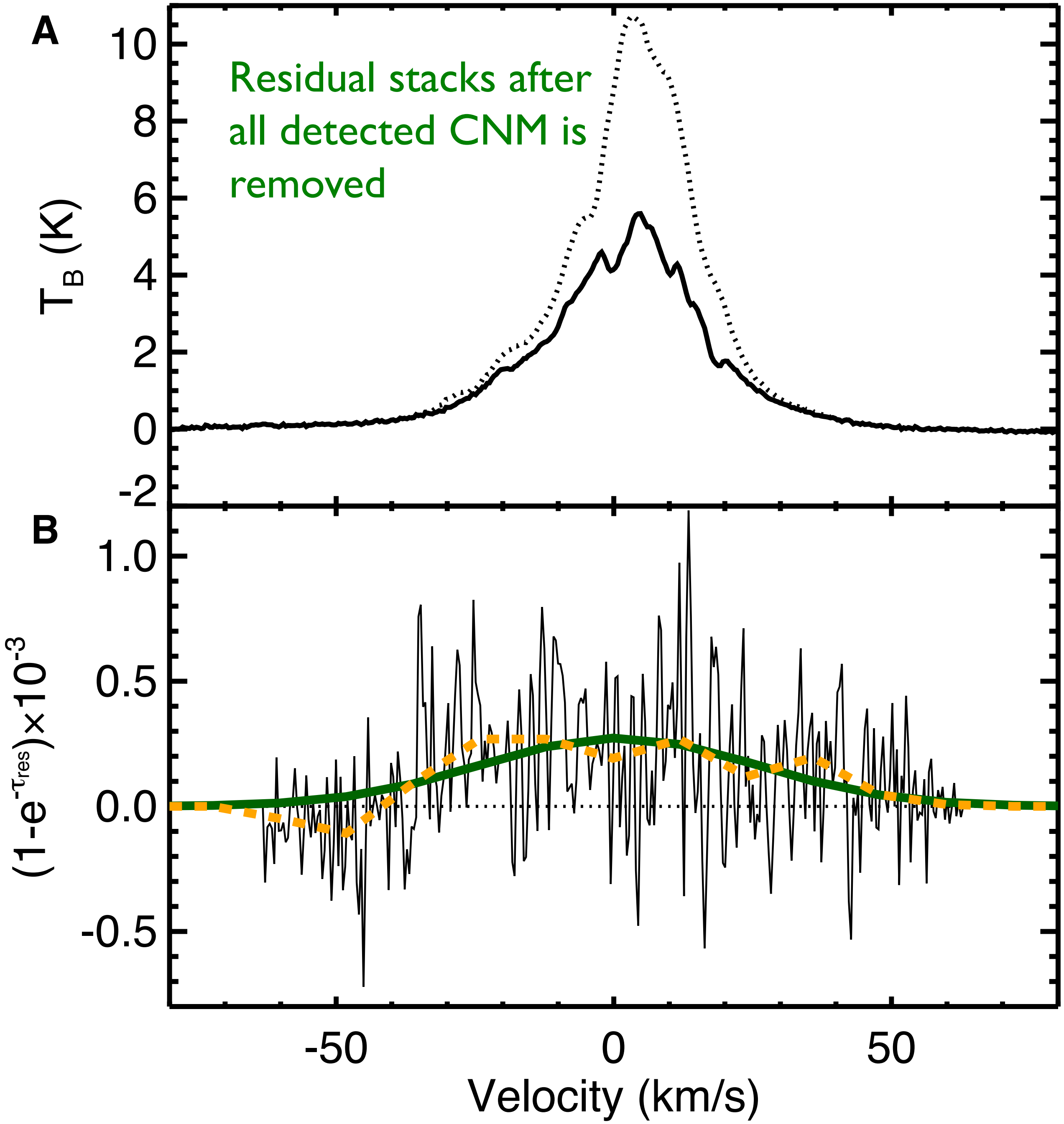



3. Remove detected components and shift by the first velocity moment of residual emission




4. Weight by 1/noise and stack



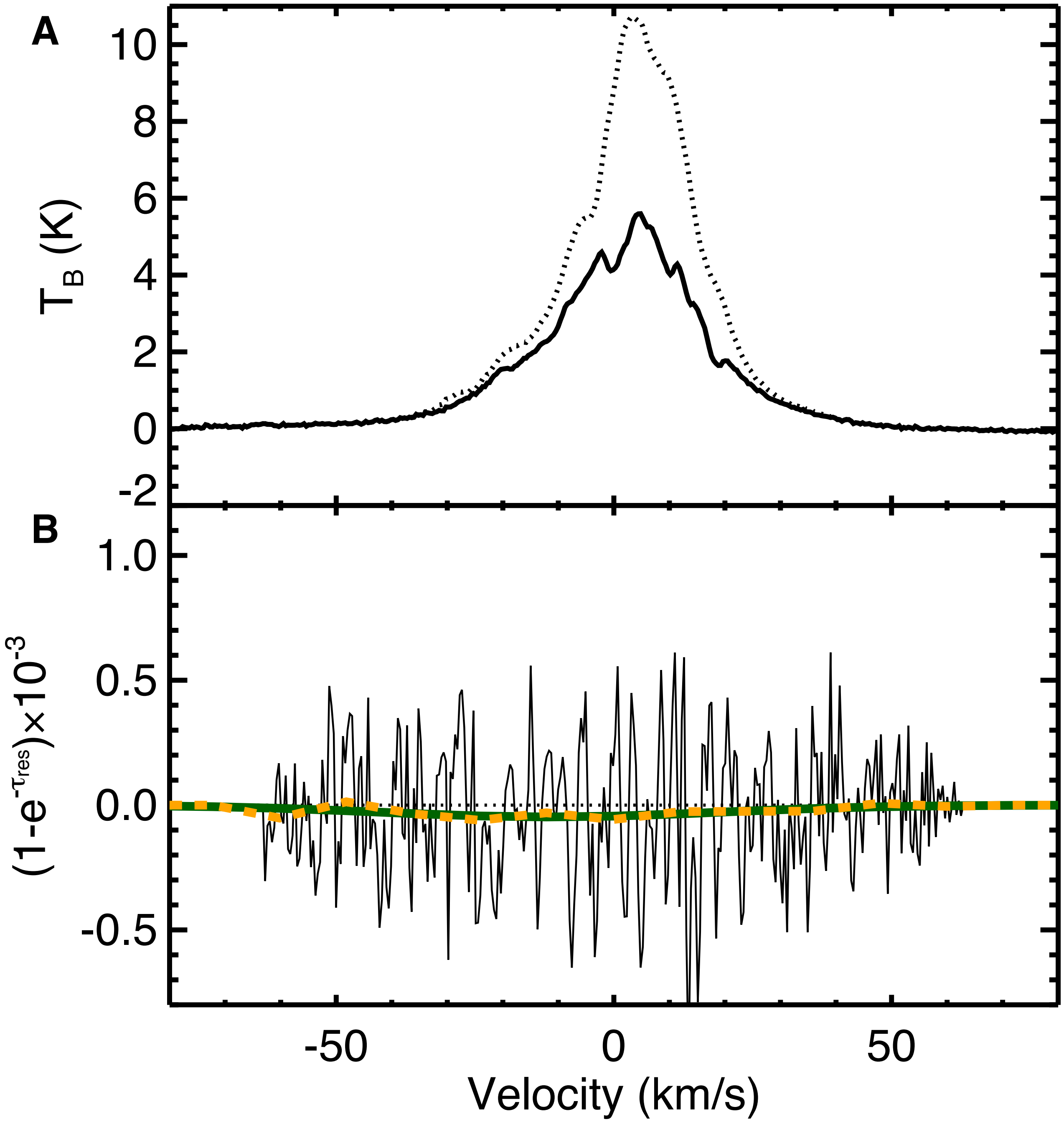

# 21-

## Stacking analysis of 19 HI absorption spectra

Broad, weak residual absorption:

Peak $\tau = 3\times10^{-4}$
FWHM ~50 km/s
Ts ~7200 (+ 1800 – 1200) K
$N(HI)\sim2\times10^{20}$ cm$^{-2}$

Prva statisticka detekcija WNM-a!

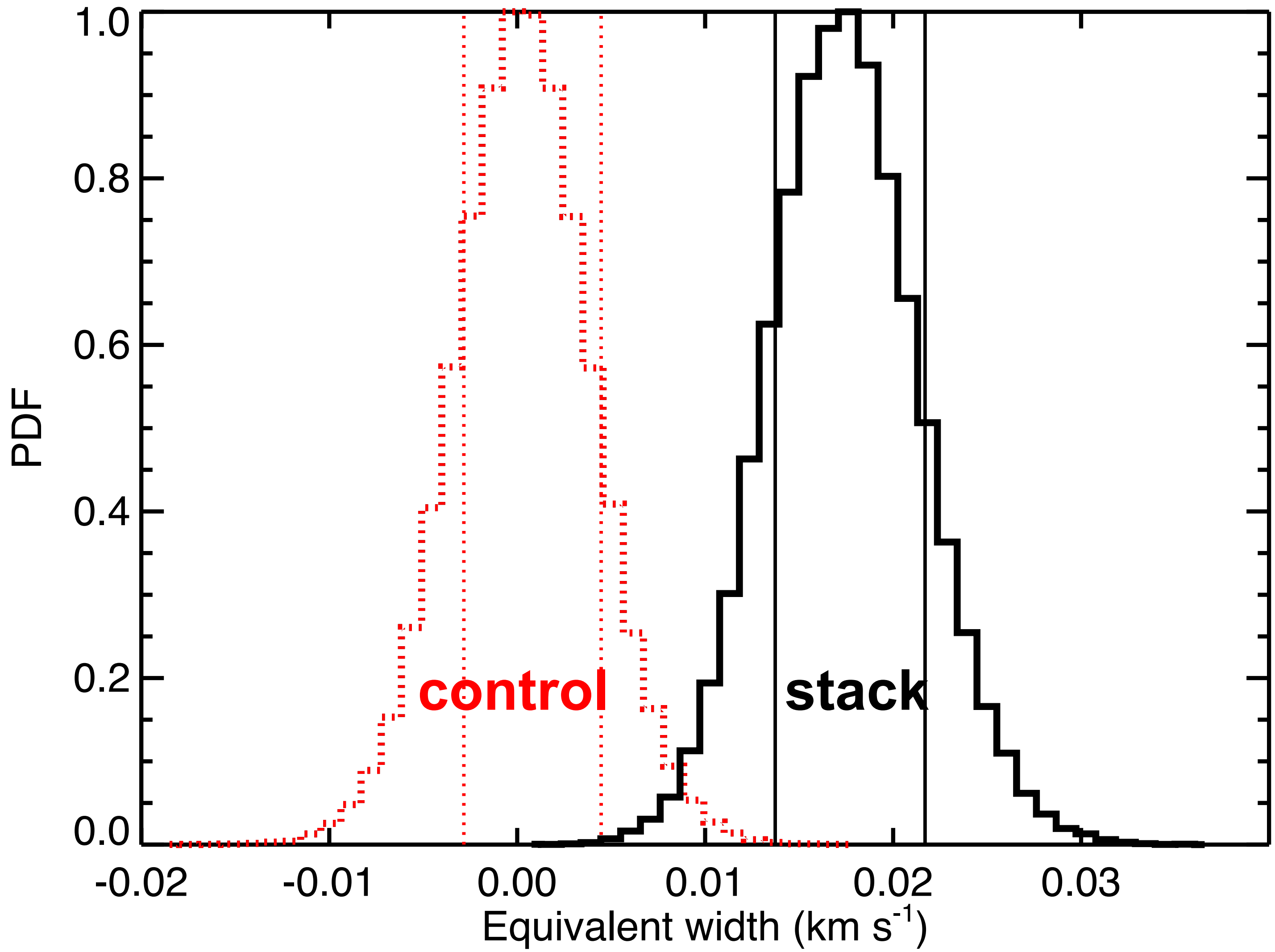



“Control” sample: stack with random velocity shifts, and/or random multiplication by (-1).

Residual absorption gone!

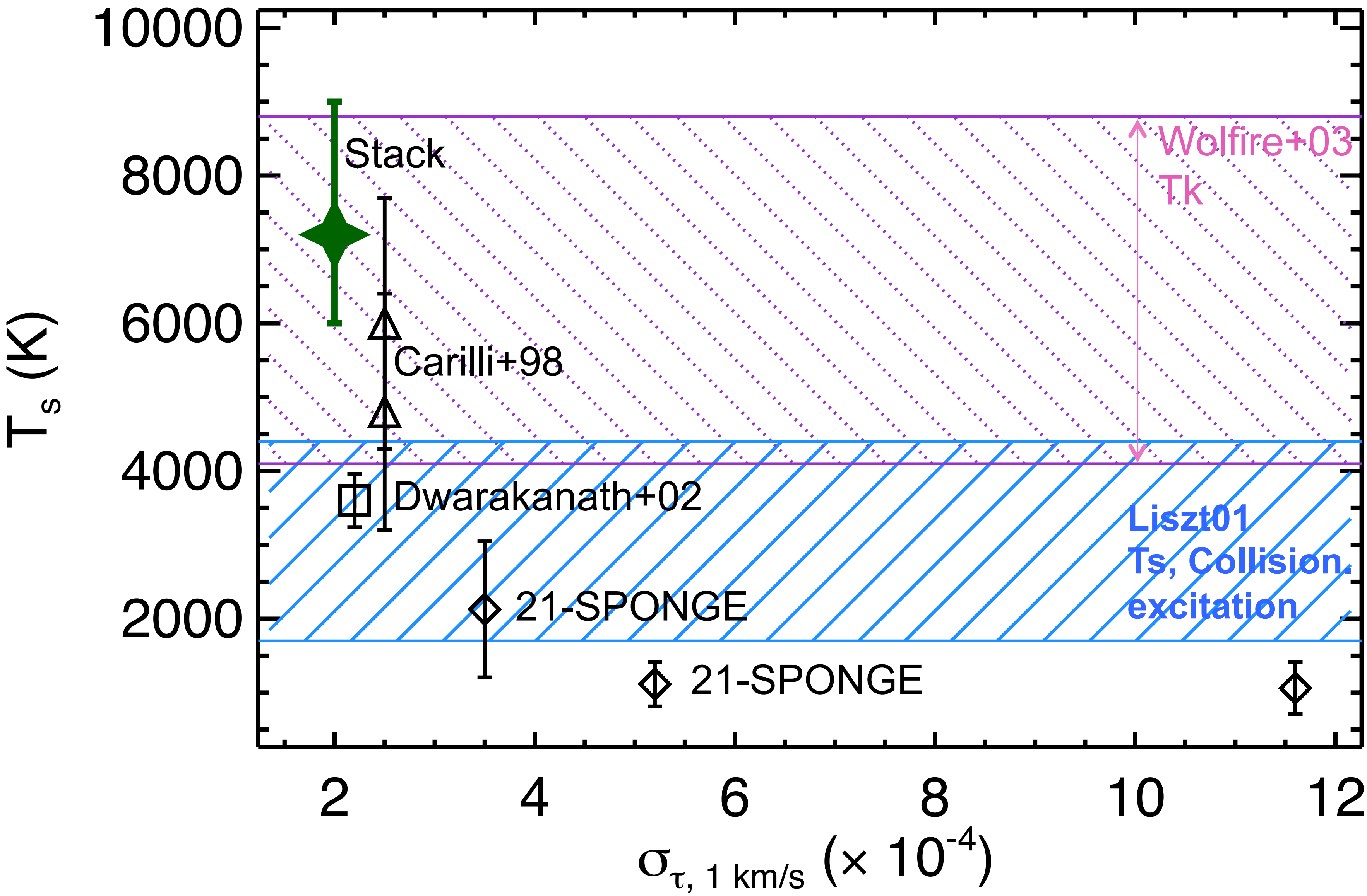
Murray, Lindner+14

# Significance of the stacked feature: ~5σ

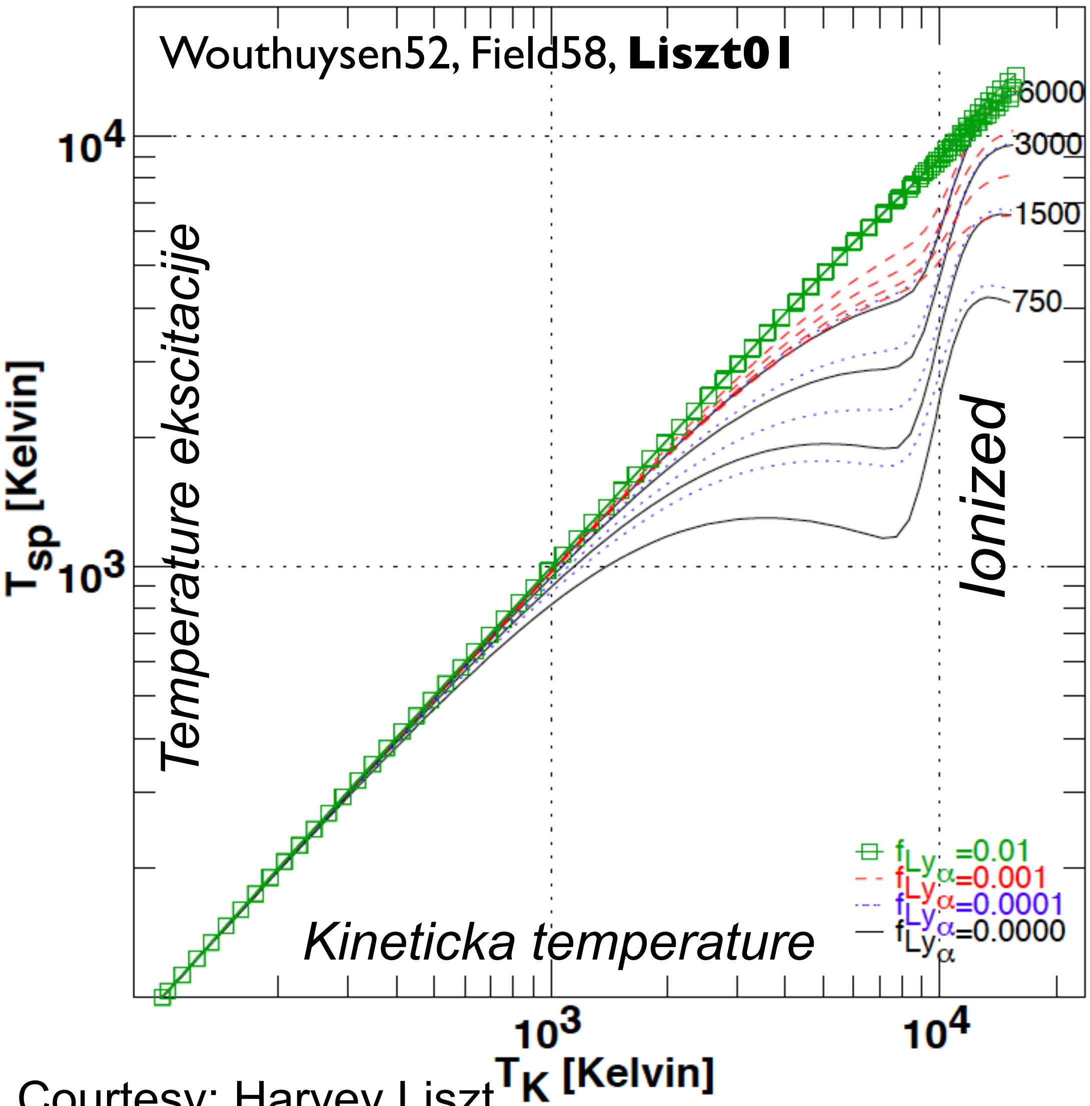



Bootstrapping → EW = 0.0182 (+ 0.0044 – 0.0036) km sec$^{-1}$

# Sva <u>direktna </u>merenja WNM temperature

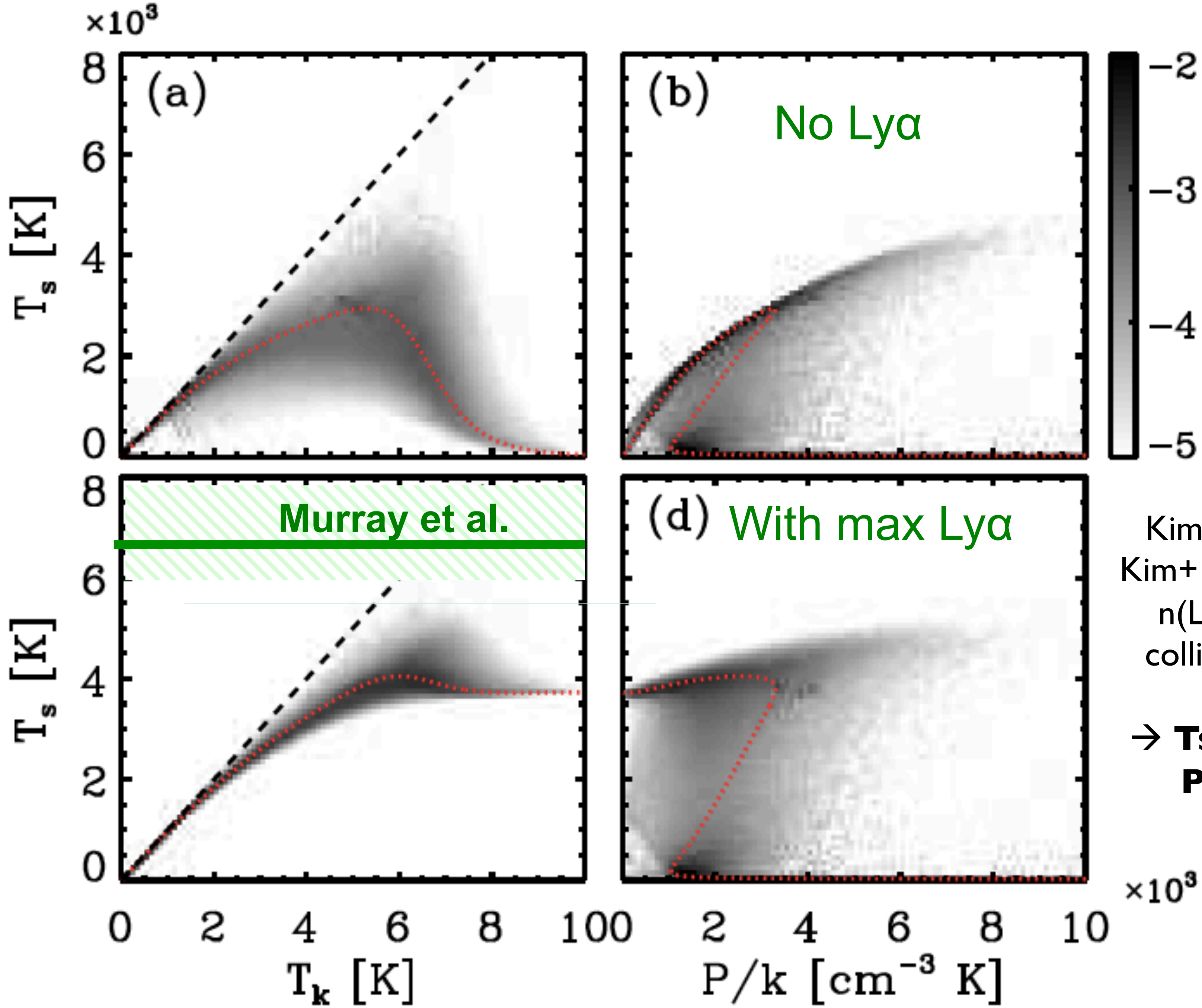


# Sudarna vs Lyα eksitacija 21-cm linije atomskog vodonika




Courtesy: Harvey Liszt

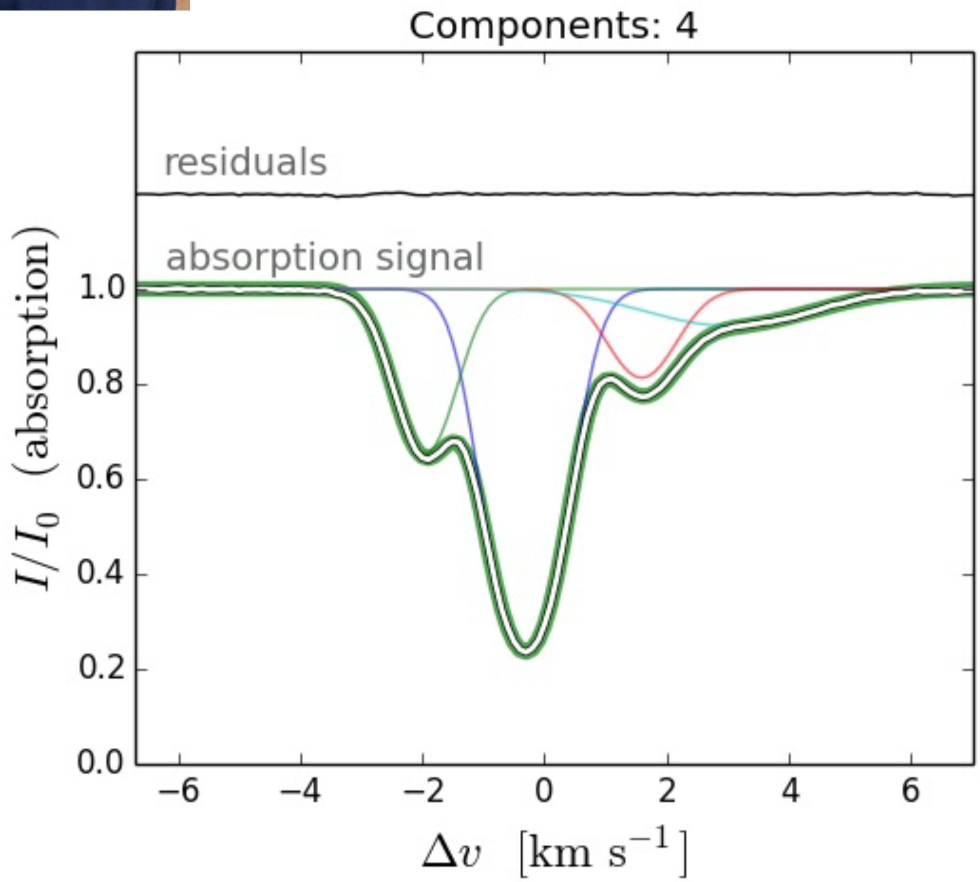
- Merimo Ts. Da bi poredili sa modelima treba nam Tk.
- Za Tk<1000 K → Ts = Tk
- Za Tk>1000 K → Ts < Tk
- Can be thermalized via radiative excitation by Lyα photons.
- Ts~7000K → Lyα ekscitacija jako znacajna ali zahteva dosta Lyα fotona
- Fraction of Lyα photons from young stars that permeates ISM is >$10^{-4}$
- Next: probe different WNM environments

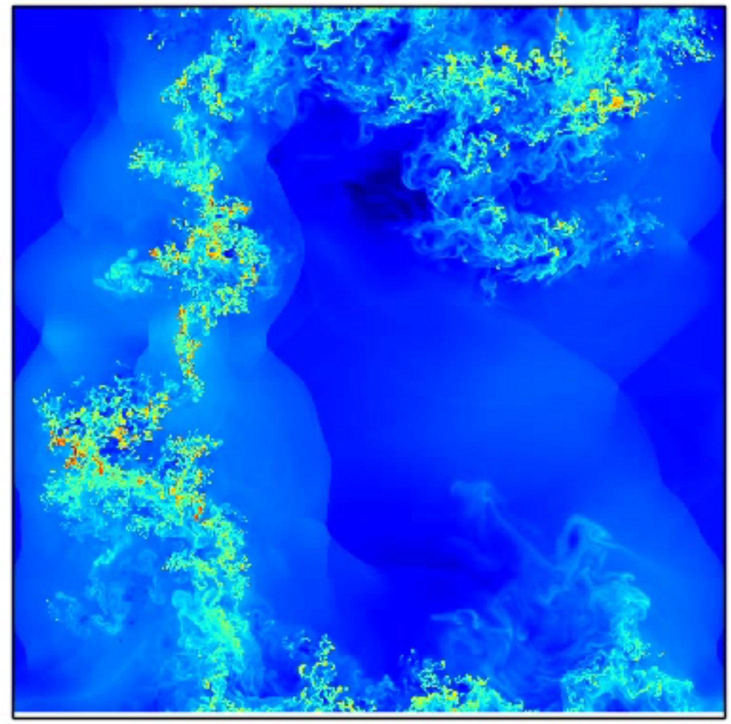



Kim, Ostriker, Kim+14: constant n(Lyα), H-H collisions only

→ **Ts<4000 K Puzzle!**

# Spektra iz numerickih simulacija: testiranje modela za formaciju molekularnih oblaka



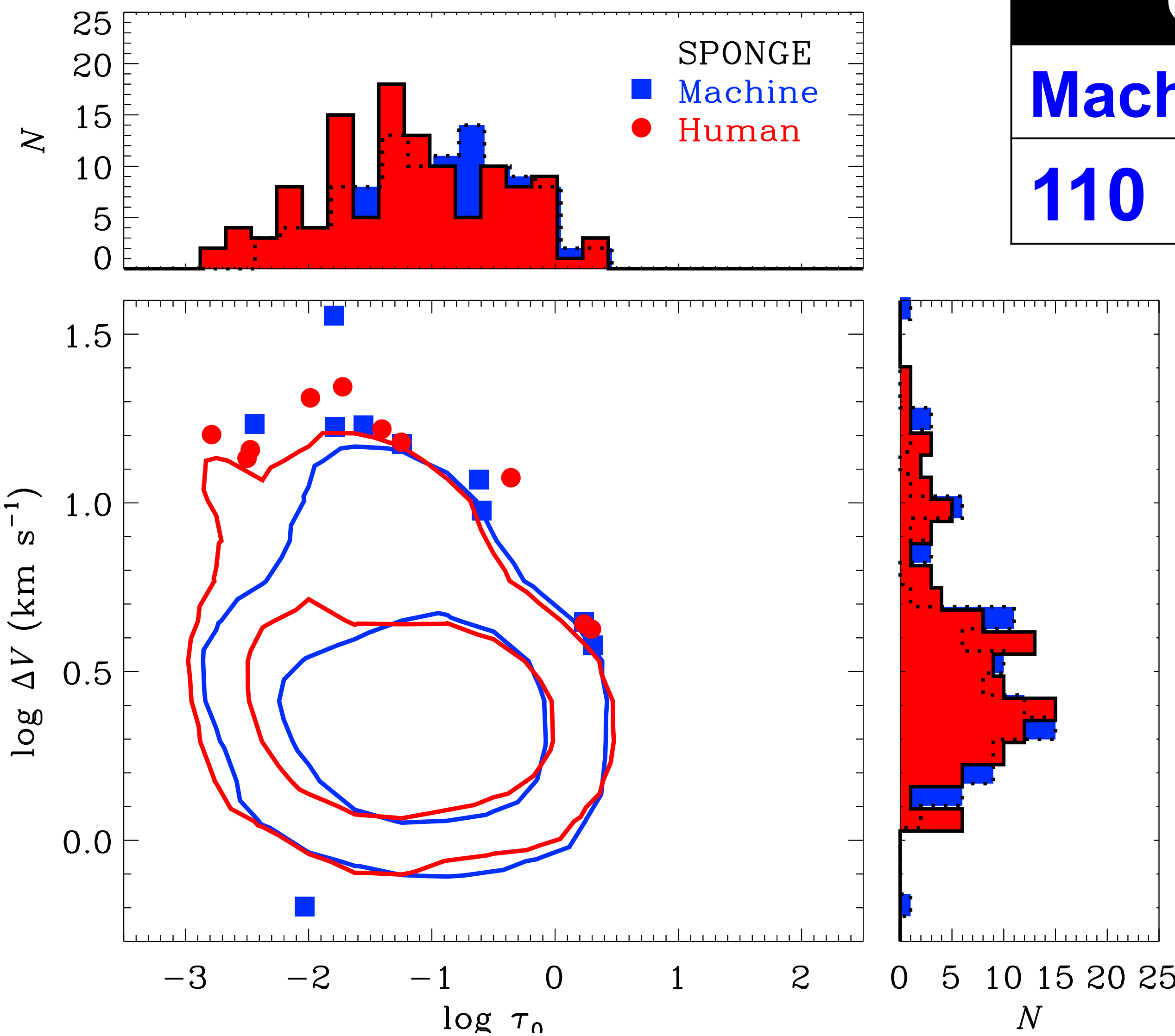



Simulation: sudarni tokovi
Hennebelle & Audit (2007)

To estimate "Guesses" of gaussian parameters calculate 2nd derivatives using a total-variation regularization approach (Lindner et al., in prep.)

# Human vs. Machine: 21-SPONGE spectra

Lindner et al. (2014, in prep)



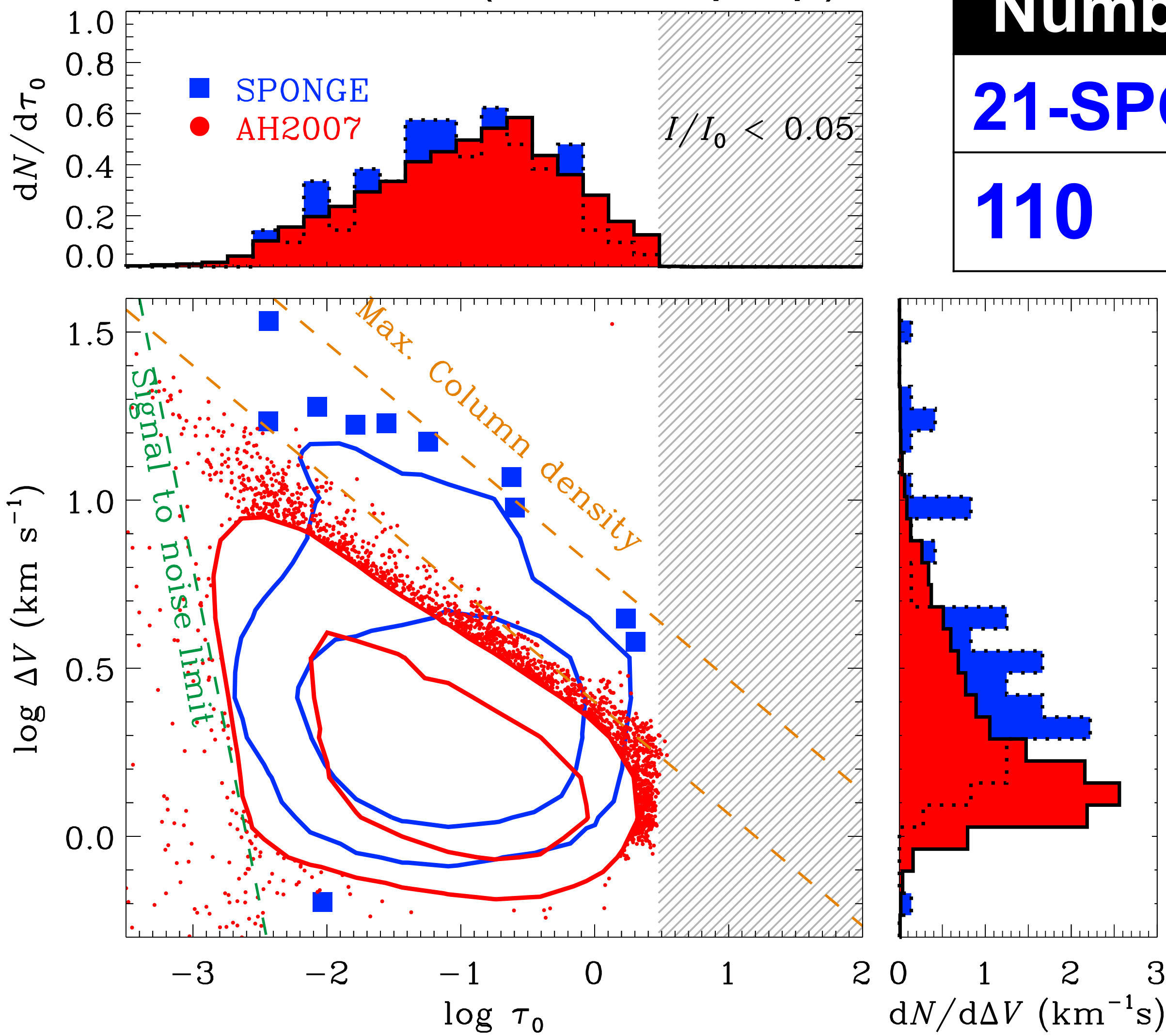

| Number of Components | |
|---|---|
| Machine | Human |
| 110 | 118 |

Odlicna saglasnost
→ Algoritam radi dobro

Spectra from
21-SPONGE survey
Murray et al. (2014, in prep)

# Observations vs. Simulation

Lindner et al. (2014, in prep)




| Number of Components | |
|---|---|
| 21-SPONGE | A&H (2007) |
| 110 | 21,883 |

Znacajna razlika!

- 21-SPONGE data from Murray et al. (2014, in prep)
- Synthetic sightlines from: Hennebelle & Audit (2007)

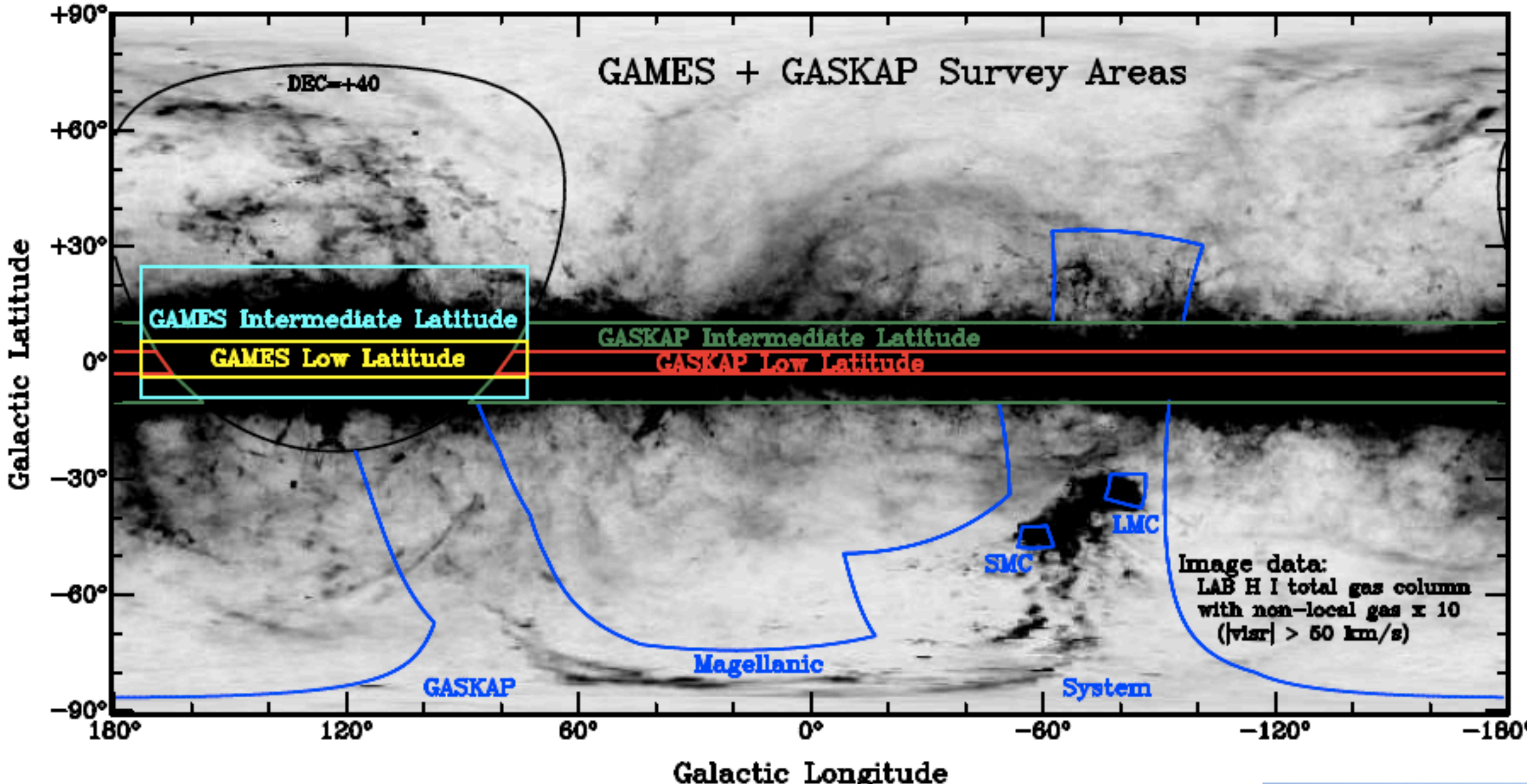
**GASKAP** (PI: Dickey)**:** MW plane + Magellanic System

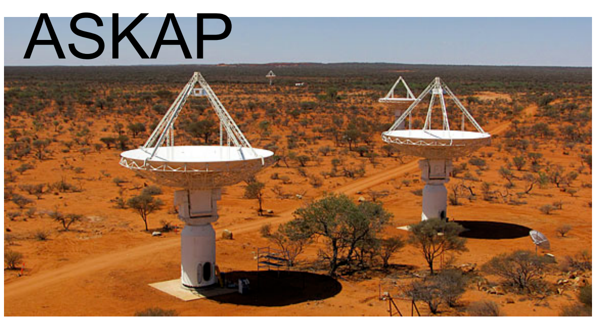
5000+ HI absorption spectra + HI+OH emission

**GAMES with WSRT**

**(northern sister survey, PI: McClure-Griffiths):**

HI absorption + HI/OH emission




**Dickey et al. (2012)**
**https://sites.google.com/site/gaskapproject/**