Put od difuznog atomskog gasa do formiranja zvezda II: HI → H_2 tranzicija

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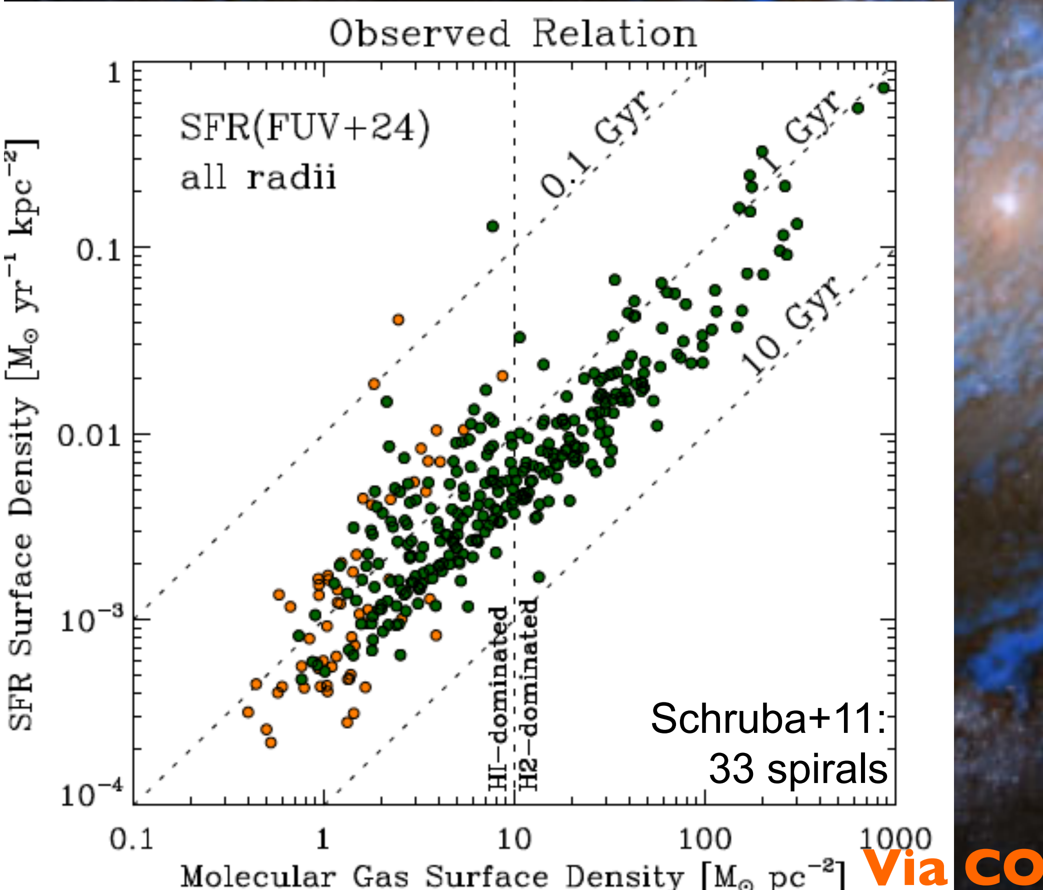
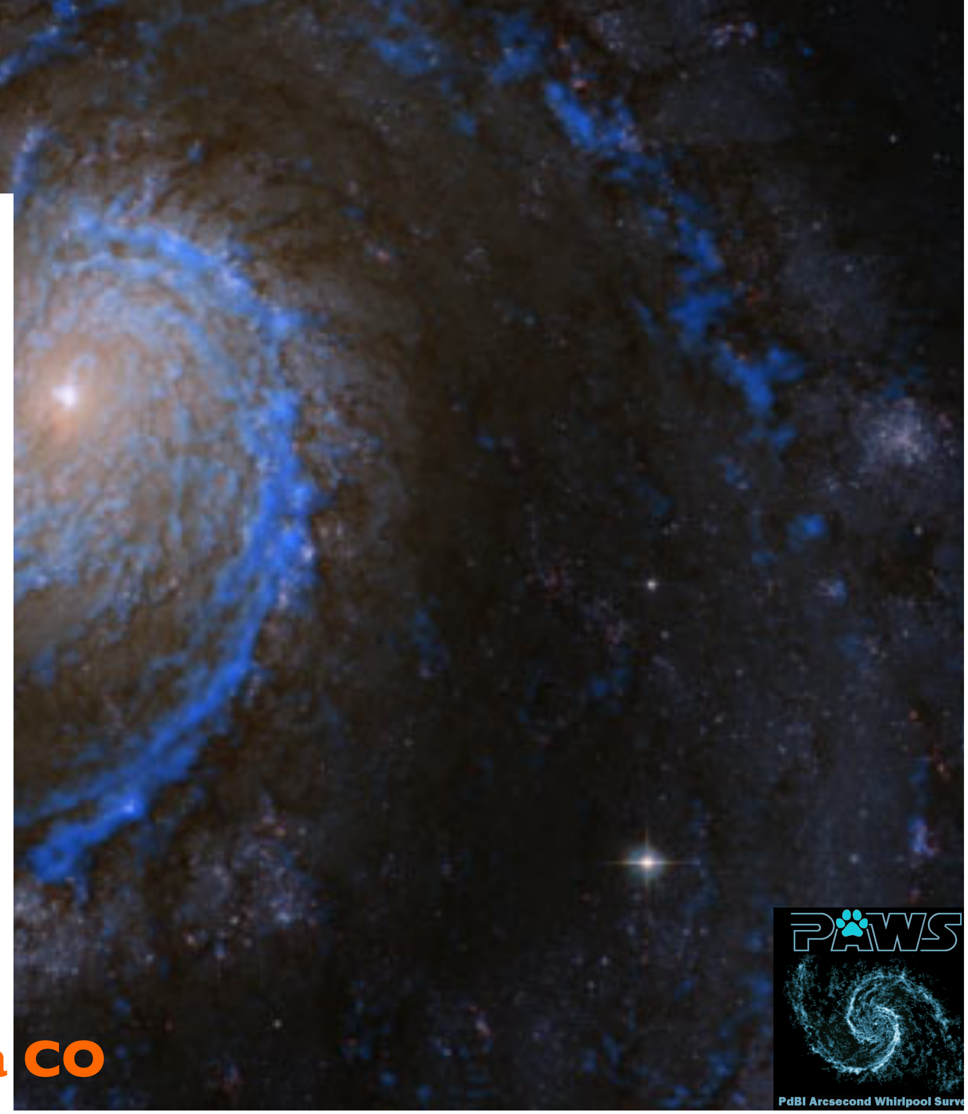
Zvezde nastaju u oblacima molekularnog gasa

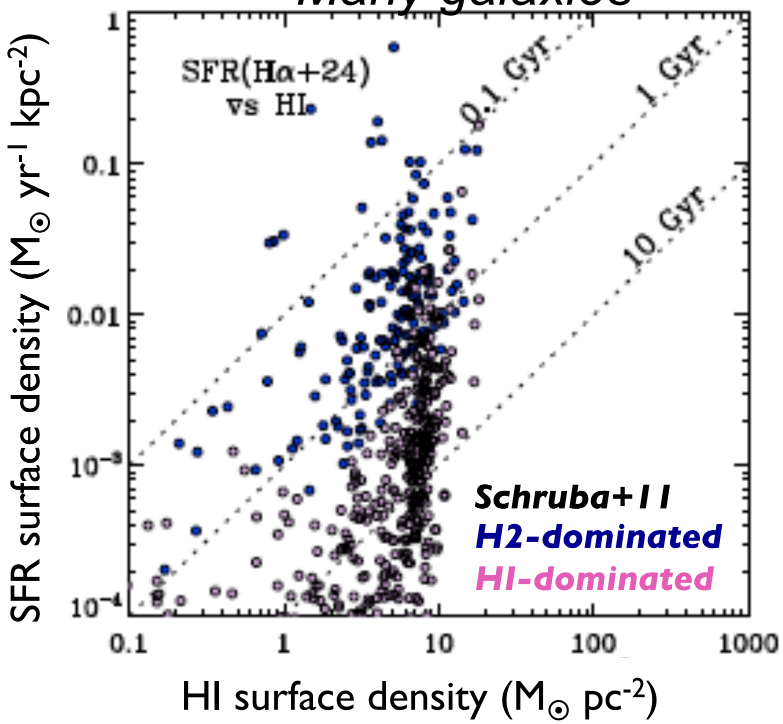
$\Sigma_{SFR} \sim \Sigma_{H2}$: Efektivnost formiranja molekularnih oblaka je kljucna stvar za evoluciju galaksija.



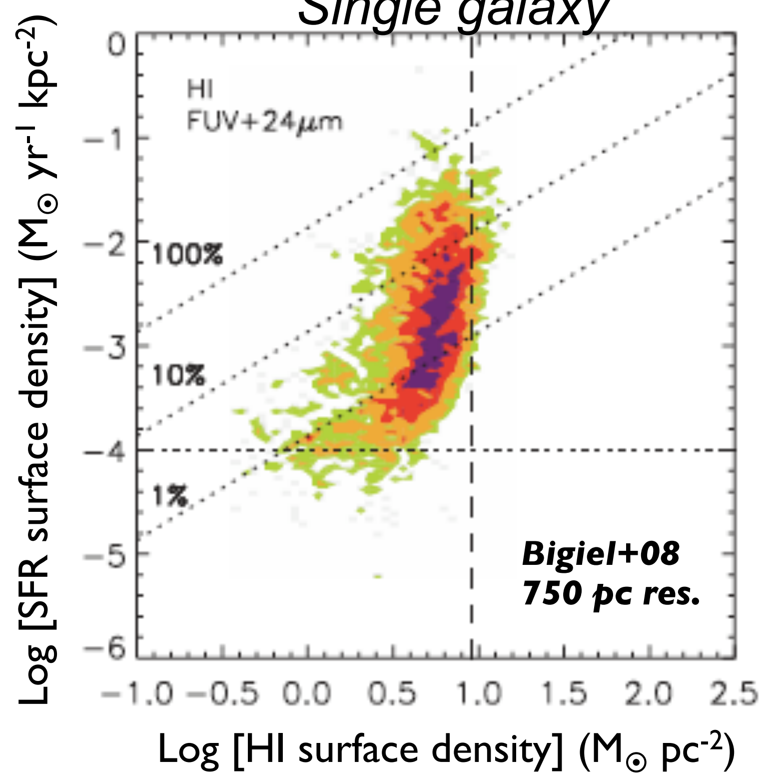


HI saturation in galaxies?

Many galaxies



Single galaxy



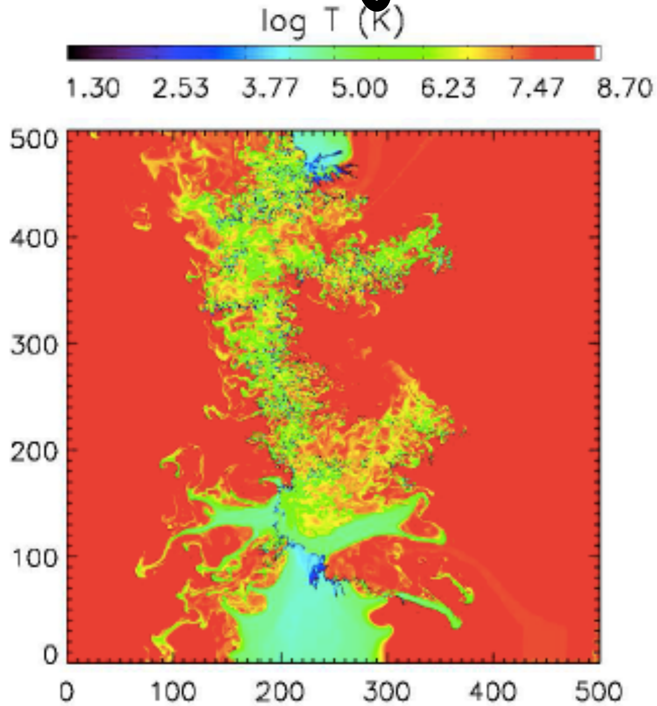
+ Wong & Blitz02; Blitz & Rosolowsky04; Schruba+11

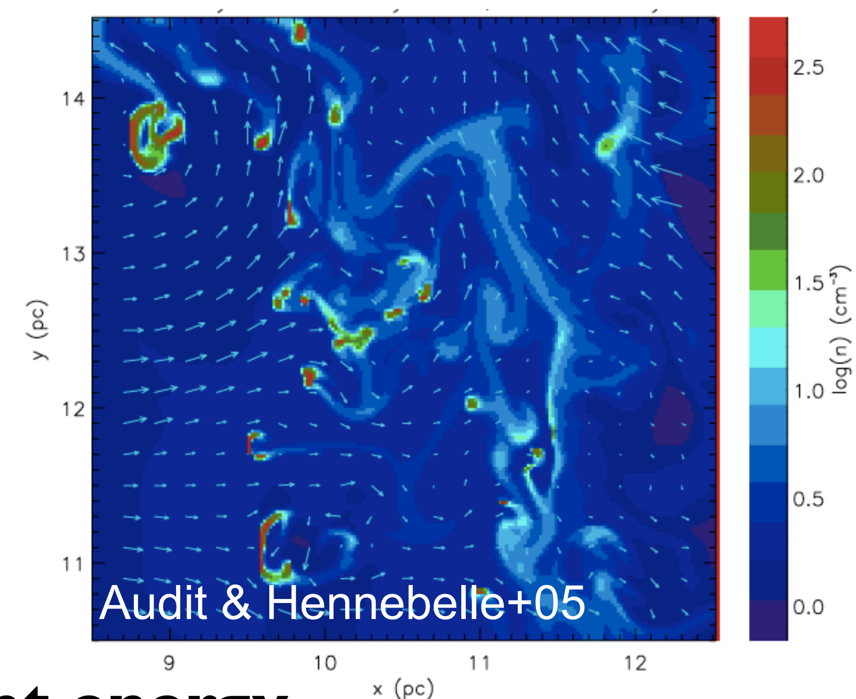
U galaksijama, na ~kpc skalama, Σ_{HI} < ~10 $M_\odot$ pc^{-2}

Uzrok: Losa resolucija posmatranja?
Uticaj hladnog HI sa τ>1?
Nagli prelaz sa HI u H_2 ?

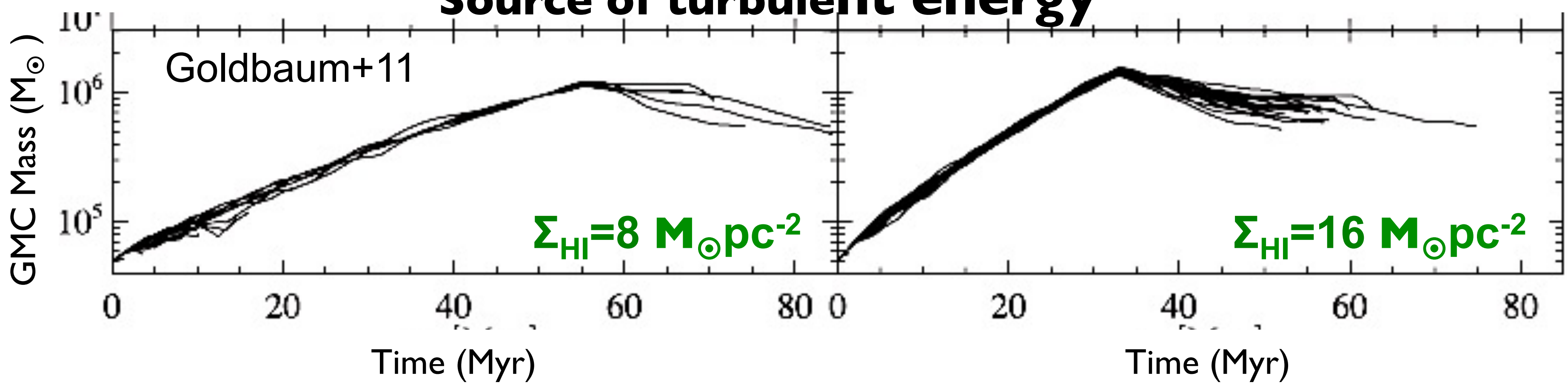
“HI halos” ili atomski omotač je važan za evoluciju molekularnih oblaka

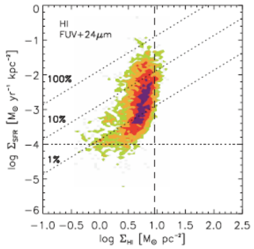
Formation reservoir (Shu73, Blitz07; Kim & Ostriker 06; Audit & Hennebelle05, Heitsch+05; Clark+12; Micic+13)



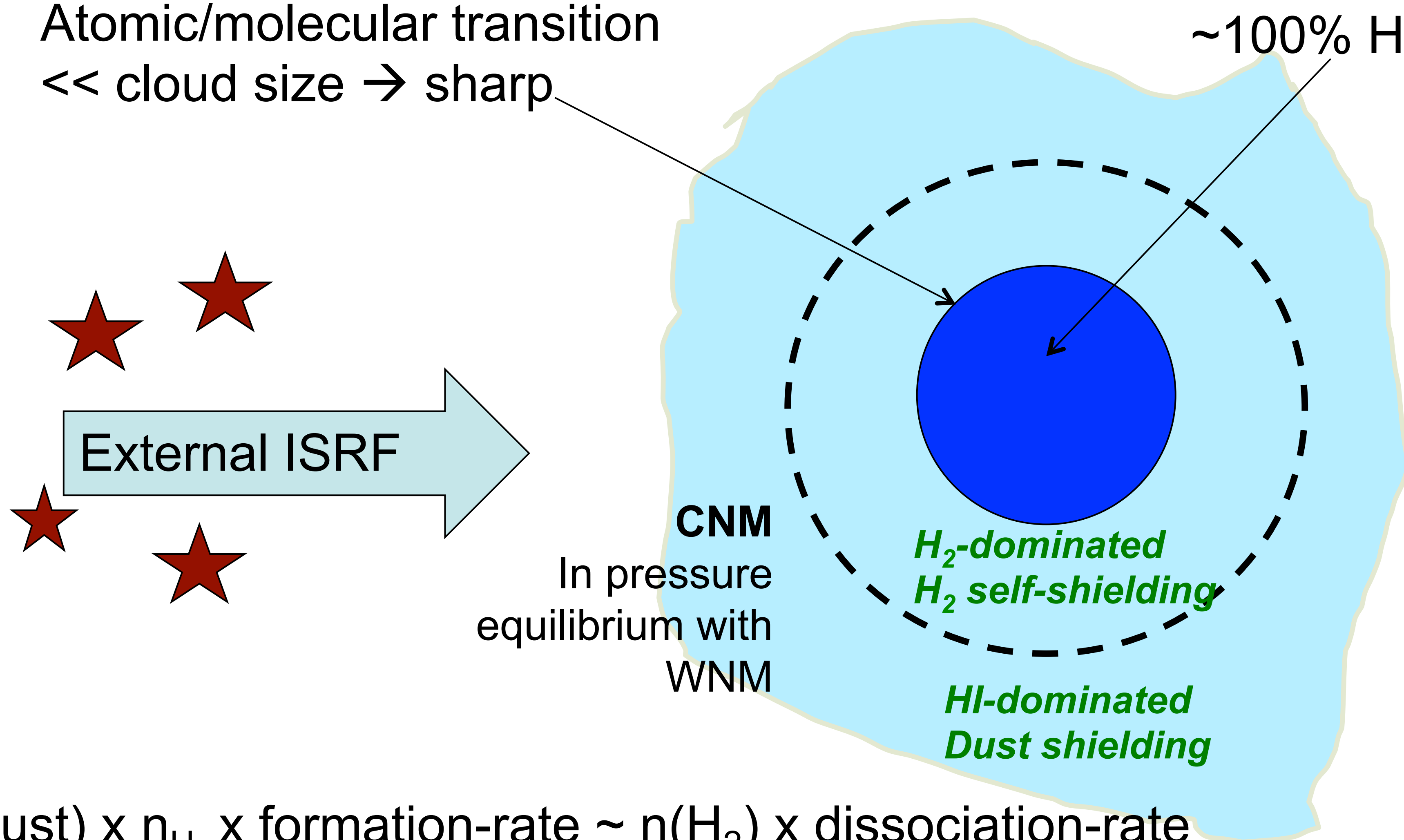


Source of turbulent energy



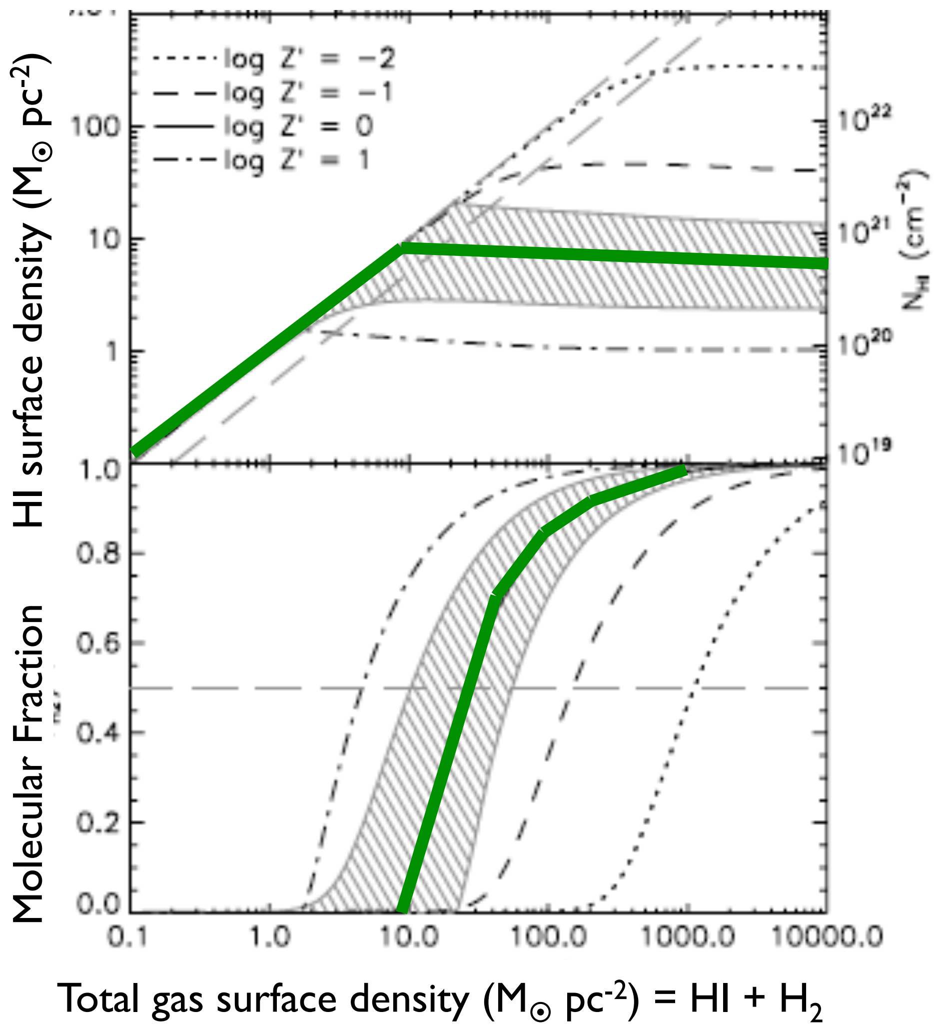


Krumholz et al. (2009): H_2 u kontekstu galaksijskih skala



n(dust) x n_H x formation-rate ~ n(H_2) x dissociation-rate

Also Ostriker+10, Mac Low & Glover 10, Spitzer & Jenkins 75



Krumholz et al. (2008, 2009)

Formiranje H_2 u ekvilibrijumu: najbitnija je zaštita H_2 molekula putum apsorpcije zračenja od strane čestica prašine (shielding) !

(A) MW: ~10 $M_\odot pc^{-2}$ of HI needed to shield H_2 from photodissociation.
$\Sigma HI = f(\Sigma tot, Z)$

↓

$\Sigma_{H2}/\Sigma_{HI} = f(\Sigma tot, Z, \Phi_{CNM}, \Phi_{mol})$

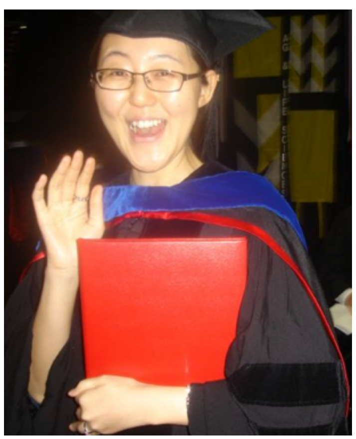
(B) Fraction of H_2 determined by:
- total gas surface density
- metallicity

ISRF does not play a significant role

Sadržaj:

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

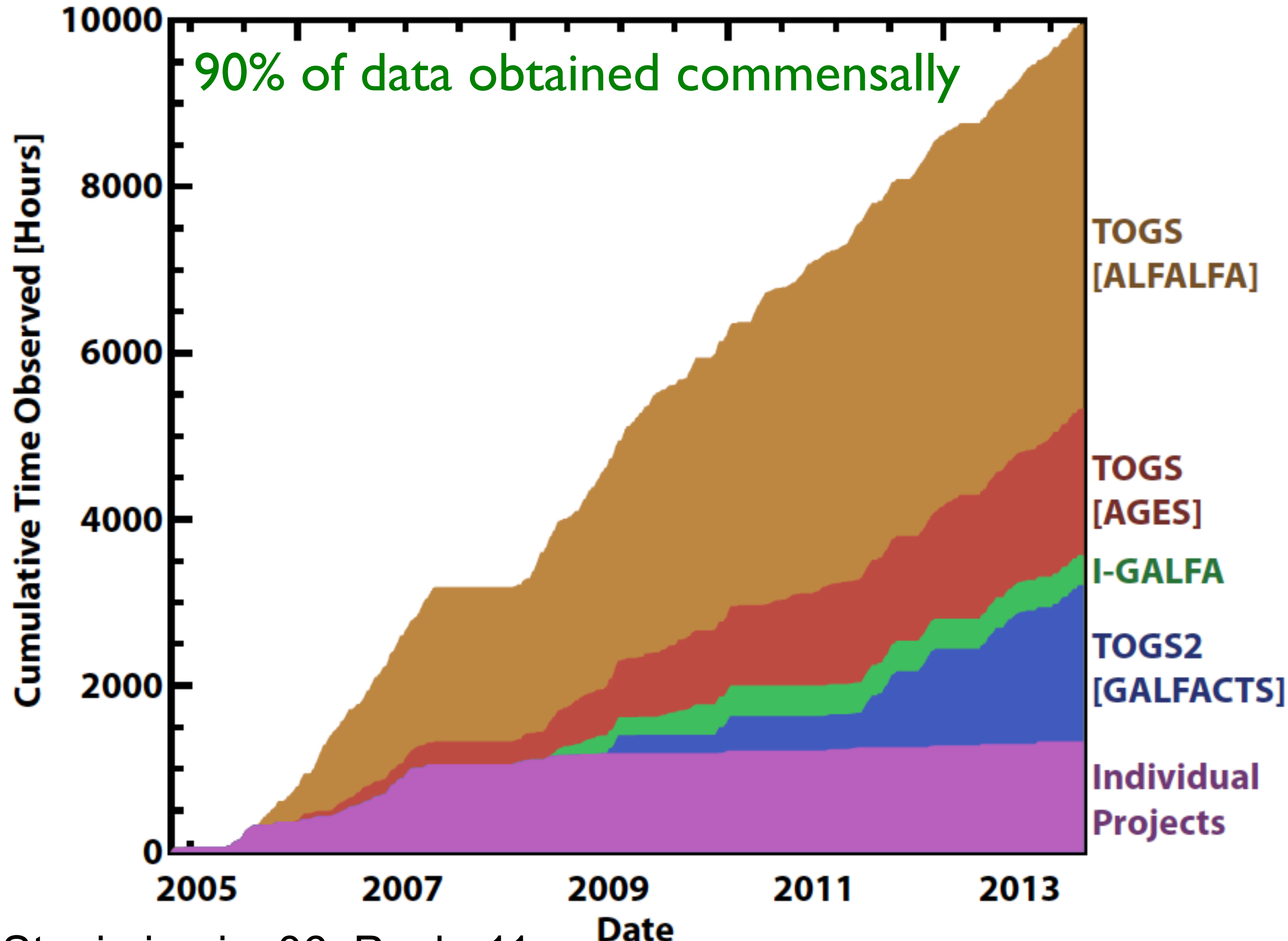


2. HI-H_2 tranzicija i Xco u Persej molekularnom oblaku:

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, A. Leroy, R. Shetty, S. Glover, F. Molina, R. Klessen

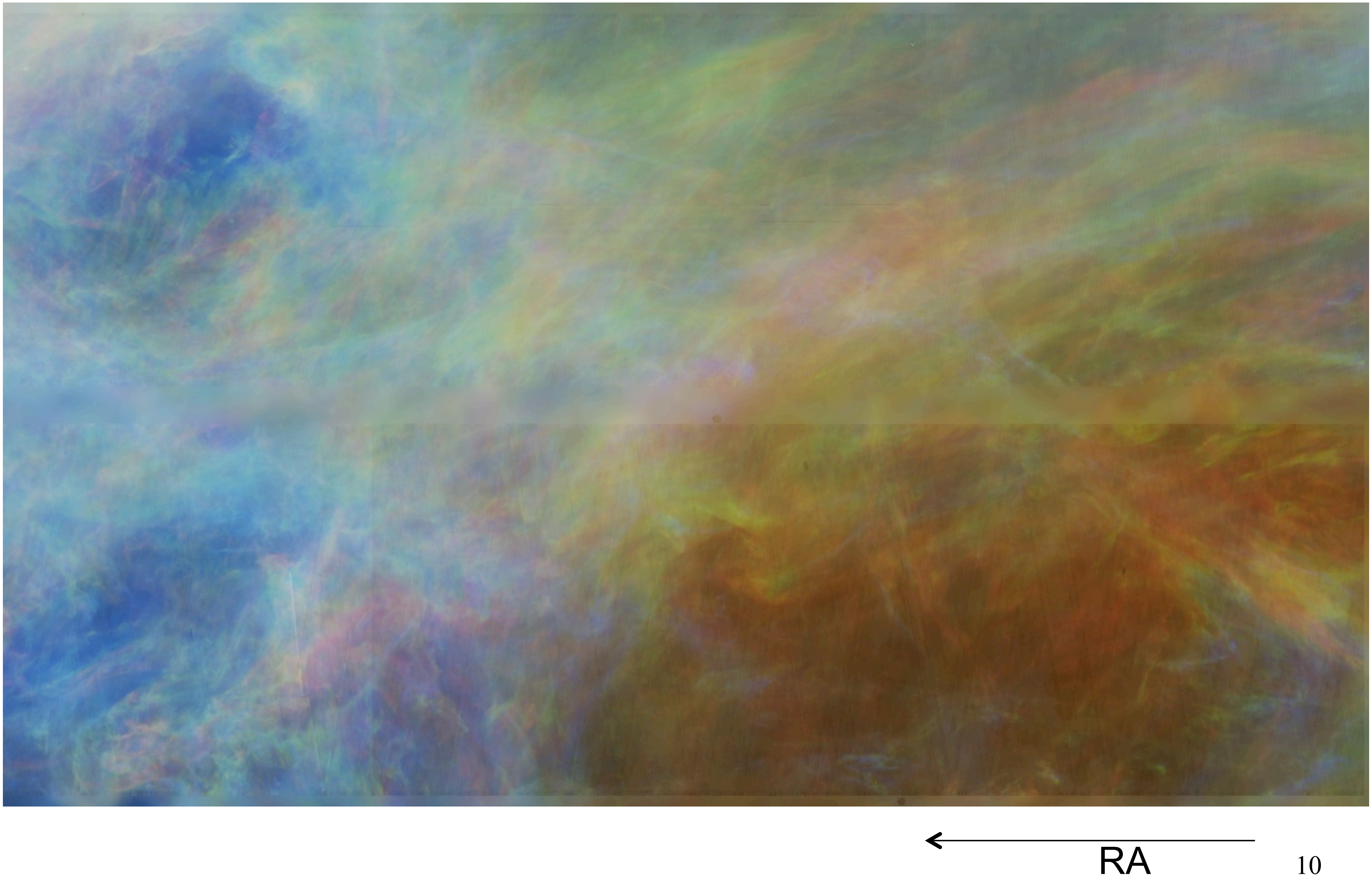

GALSPECT:
Wertheimer, Mock et al.
ALFA
GALFA HI

>10,000 sati posmatračkog vremena



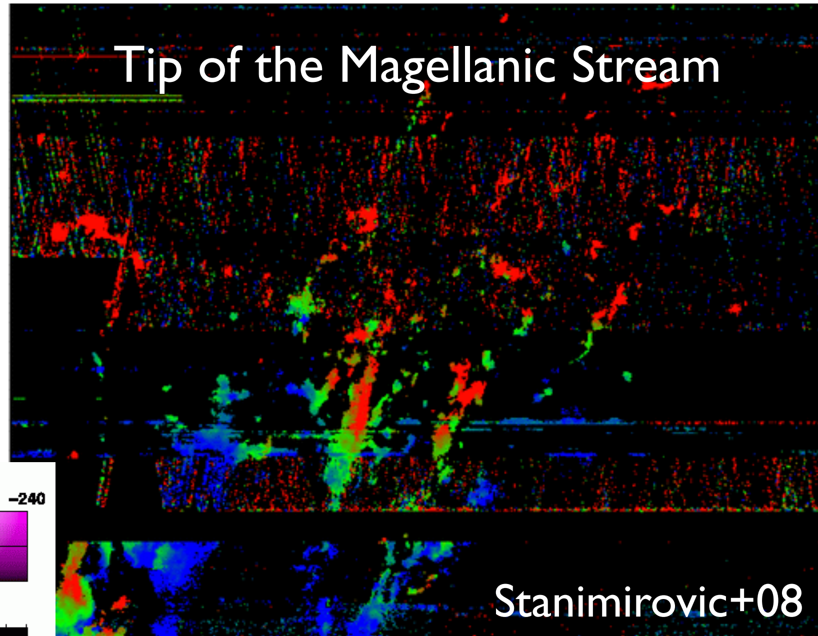
Stanimirovic+06, Peek+11

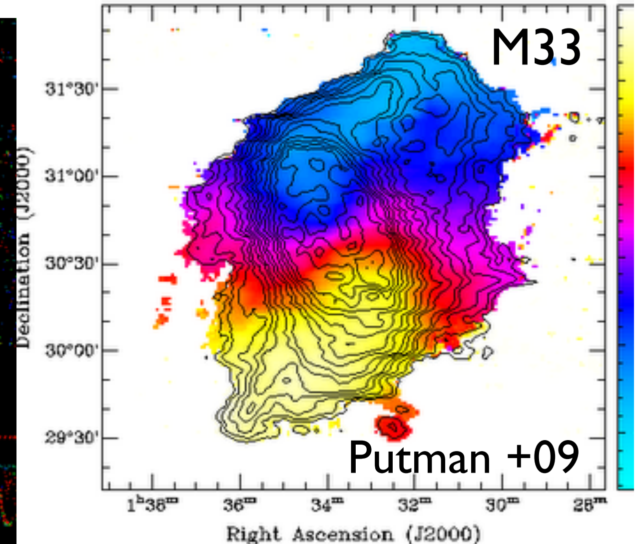
GALFA-HI od 2005: 13,000 deg^2

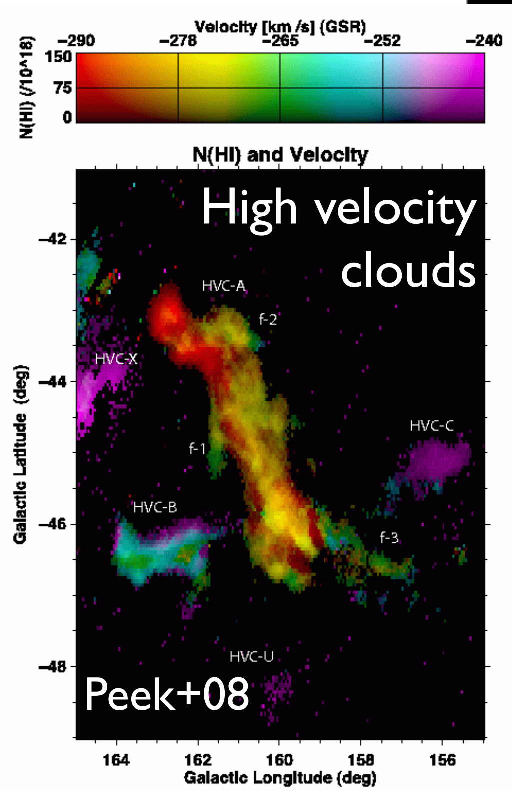


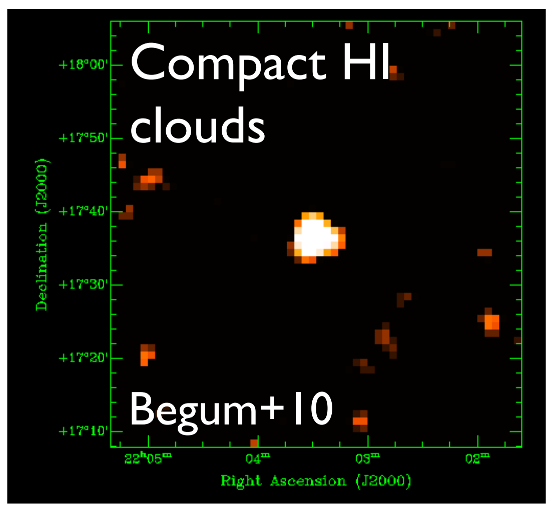
Special thanks to Josh Peek, Brian Babler, Kevin Douglas & GALFACTS

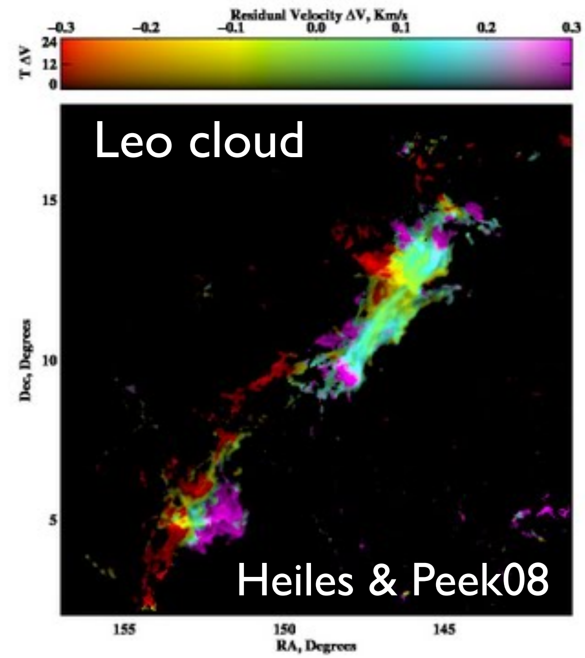
GALFA-HI science: 20+ papers

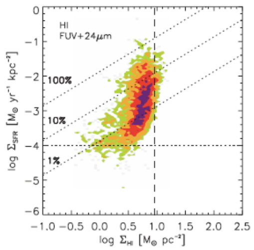






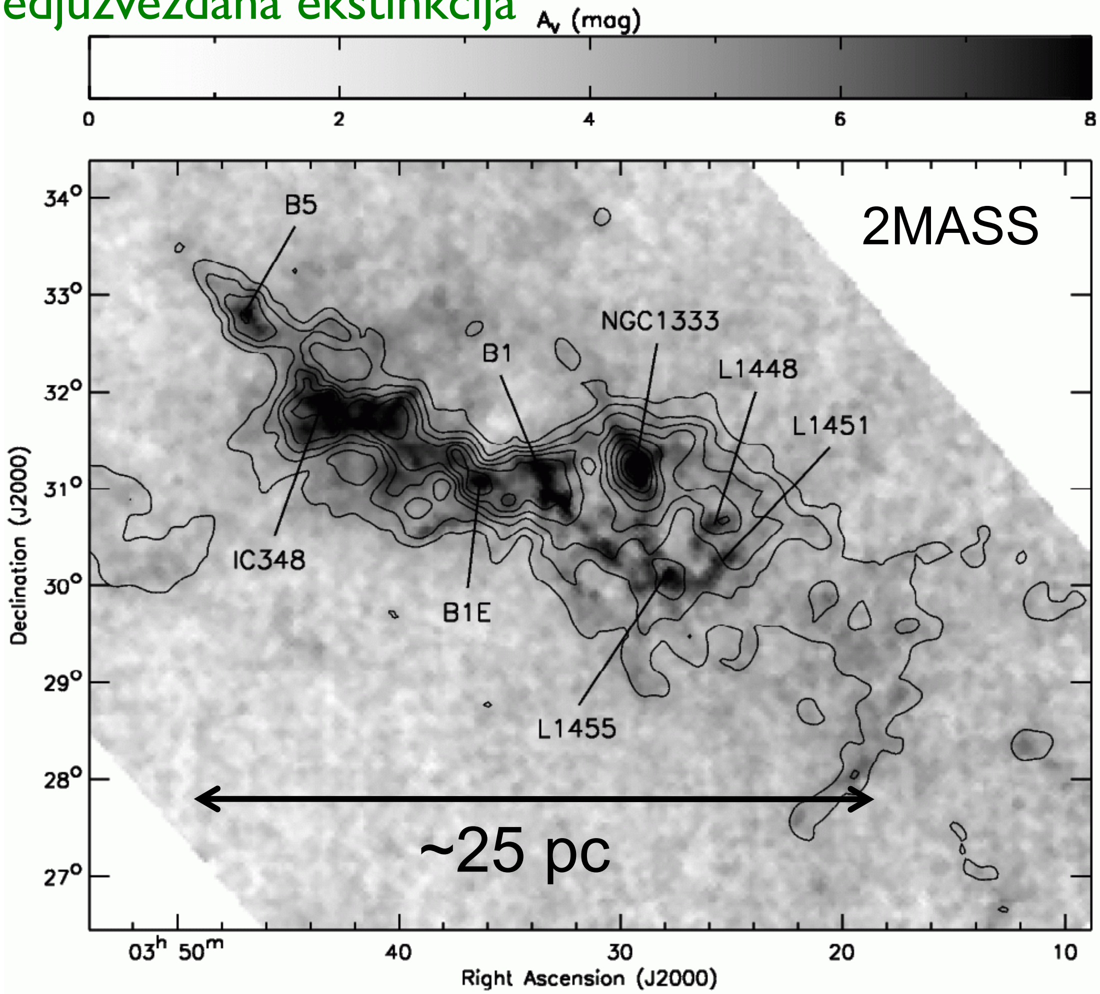






Zoom-in on the HI halo in Perseus

Medjuzvezdana ekstinkcija



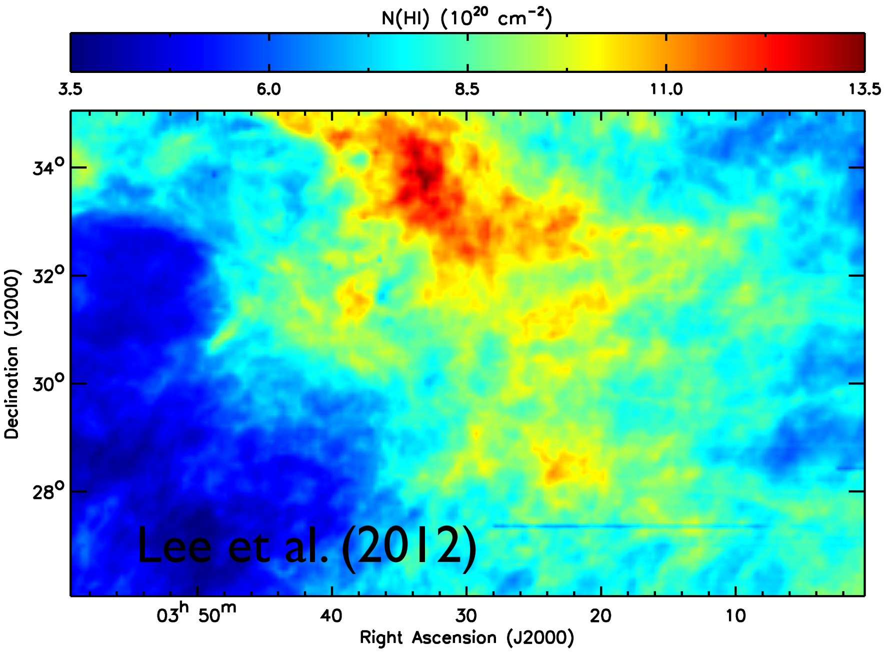
GALFA-HI: HI na rezoluciji od 3.5'

D = 200 – 350 pc, M ~10^4 $M_\odot$; Intermediate SFR
Age~10 Myrs → evolved

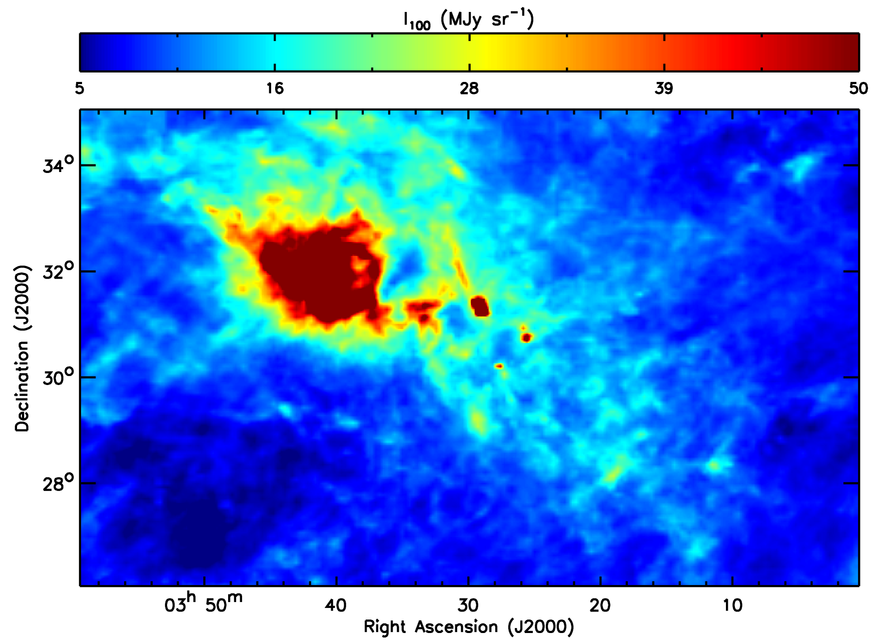
Persej molecularni oblak: procena H_2 preko IR

(D = 200 – 350 pc → Δx = 0.4 pc)

HI from GALFA-HI



H_2: IR (IRAS) + Av (COMPLETE)



H_2 u Perseju:
(D = 200 – 350 pc → l < 1 pc)

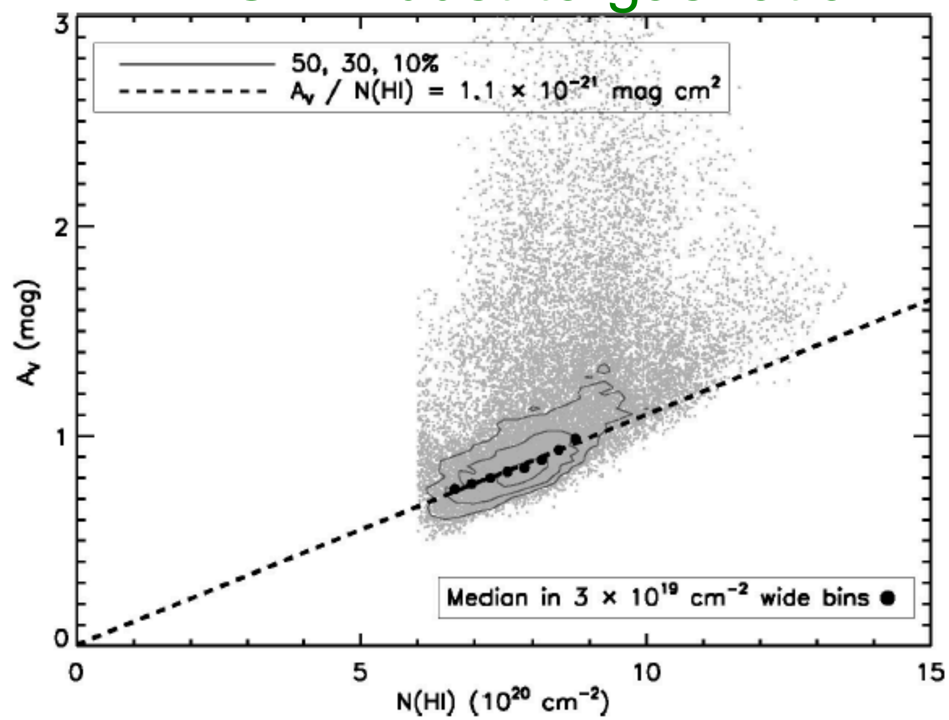
- Σ_{HI} : **GALFA-H I**
- Σ_{H2} : derived using IRIS 60, 100 μm maps, 2MASS A_V map [Schlegel et al. T_{dust} map for calibration]

$$\frac{f \times I_{60}}{I_{100}} = \left(\frac{60}{100}\right)^{-(3+\beta)} \frac{\exp(hc/\lambda_{100} kT_{dus}}{\exp(hc/\lambda_{60} kT_{dust}}$$

Calibration to Schlegel et al. T_{dust} map

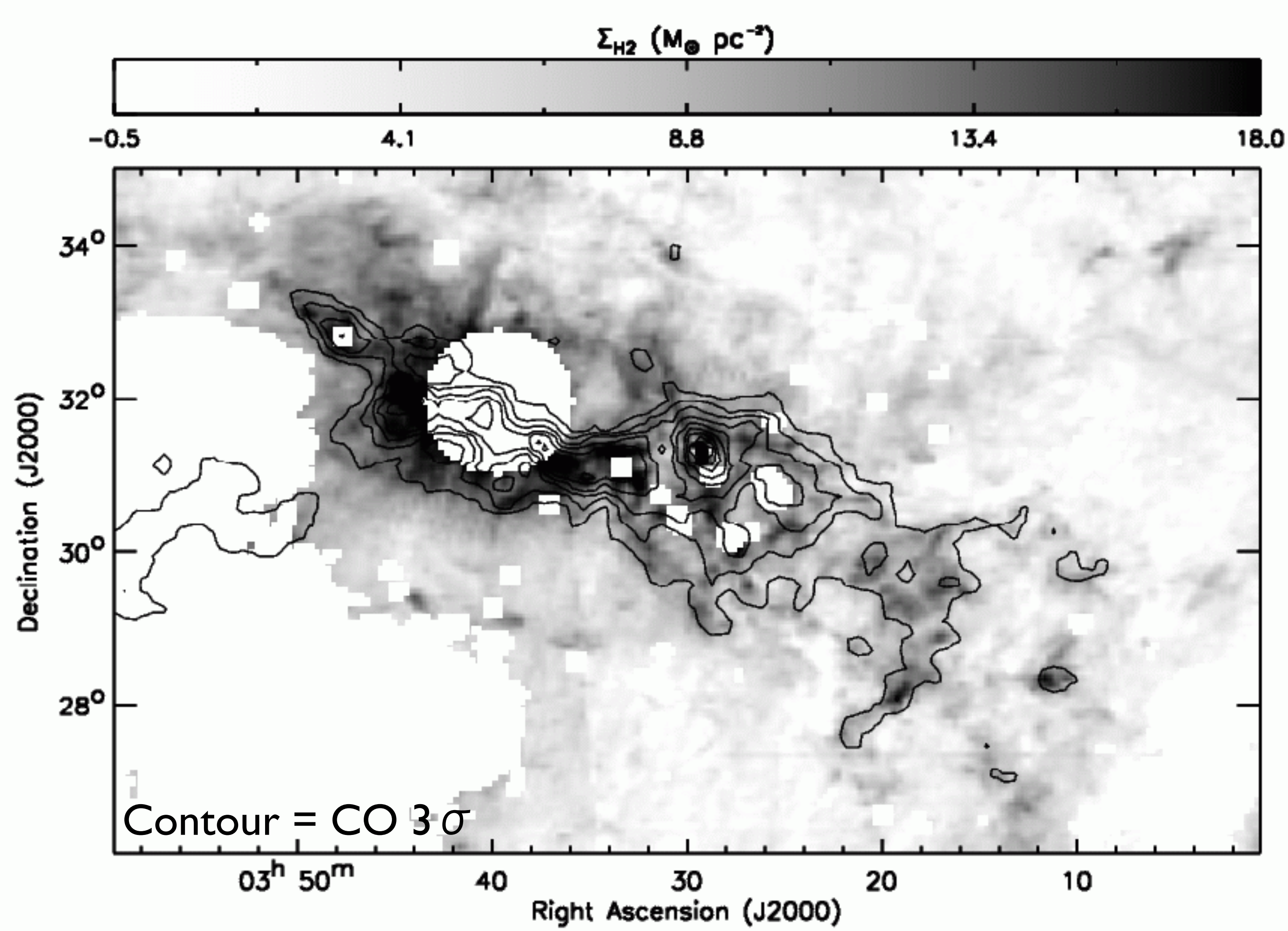
$$N(\mathrm{H_2}) = \frac{1}{2}\left(\frac{A_V}{\mathrm{DGR}} - N(\mathrm{HI})\right)$$

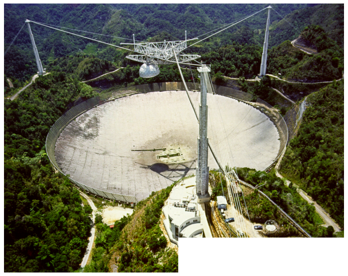
DGR = dust-to-gas ratio



Persej molecularni oblak: H_2 preko IR:

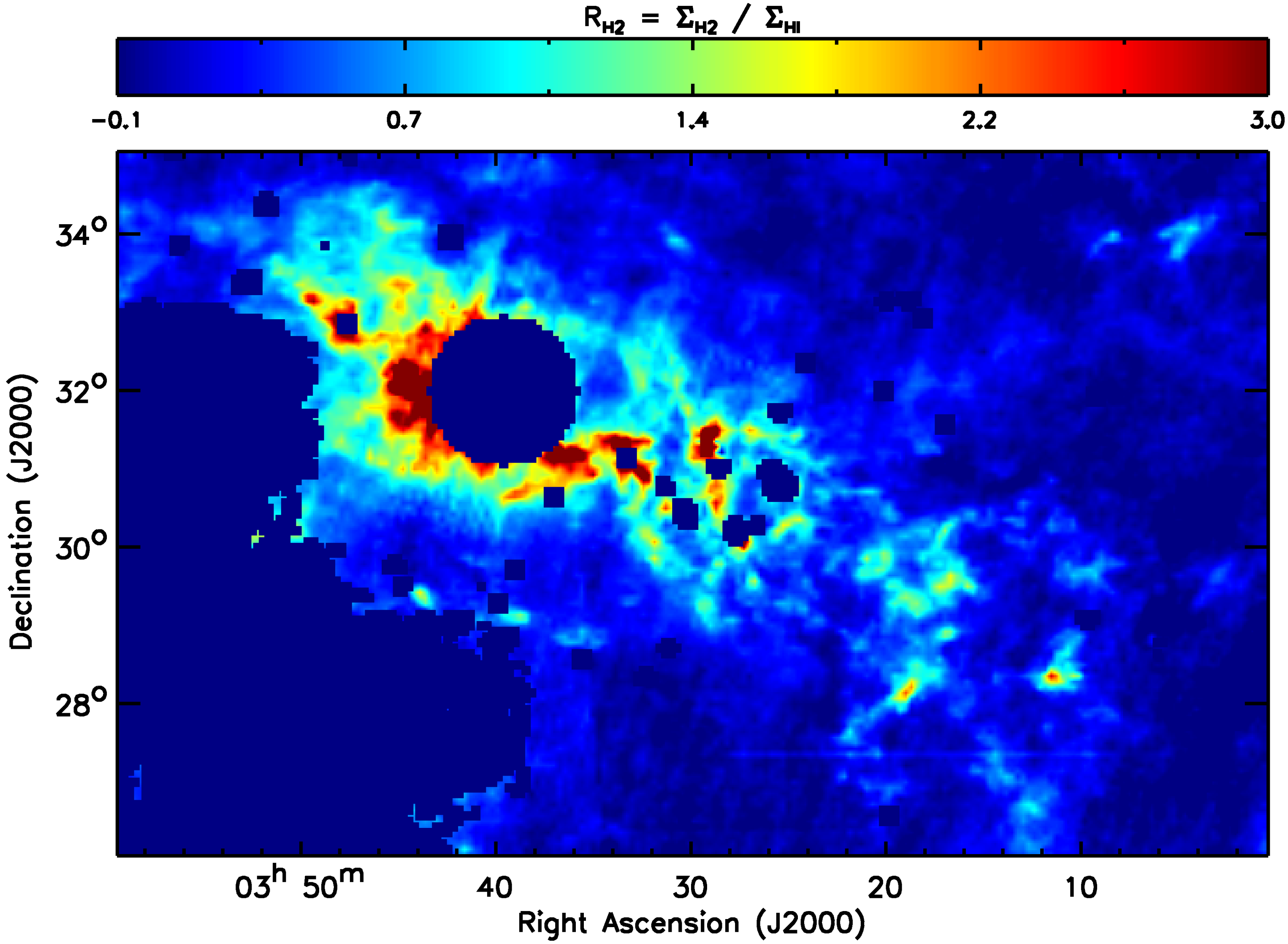
(D = 200 – 350 pc → Δx = 0.4 pc)





Persej molecularni oblak: H_2 preko IR:

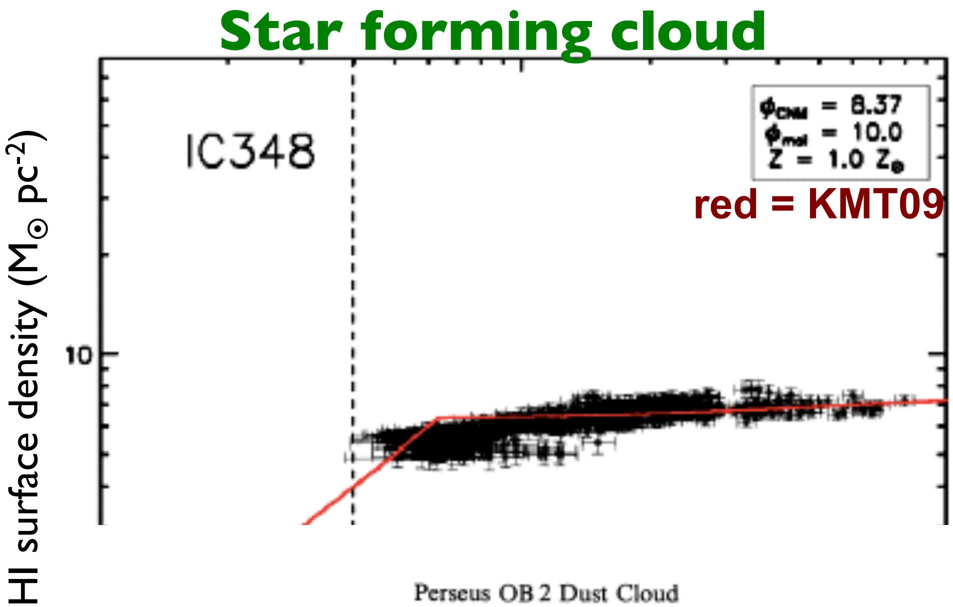
(D = 200 – 350 pc → Δx = 0.4 pc)

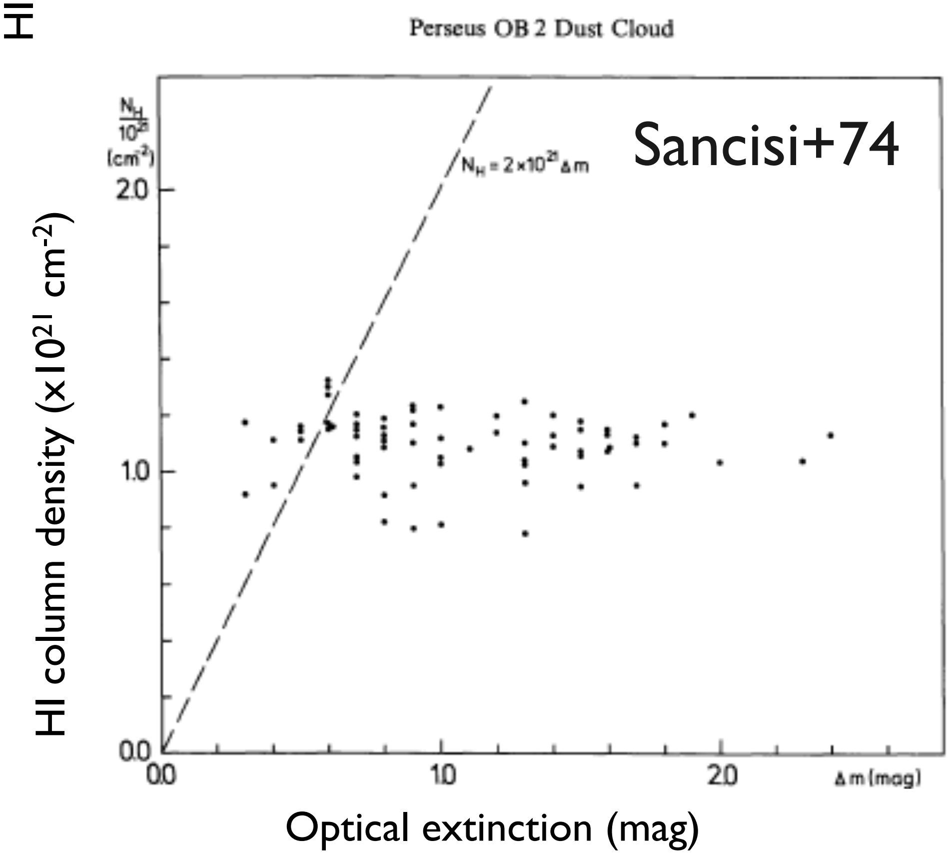


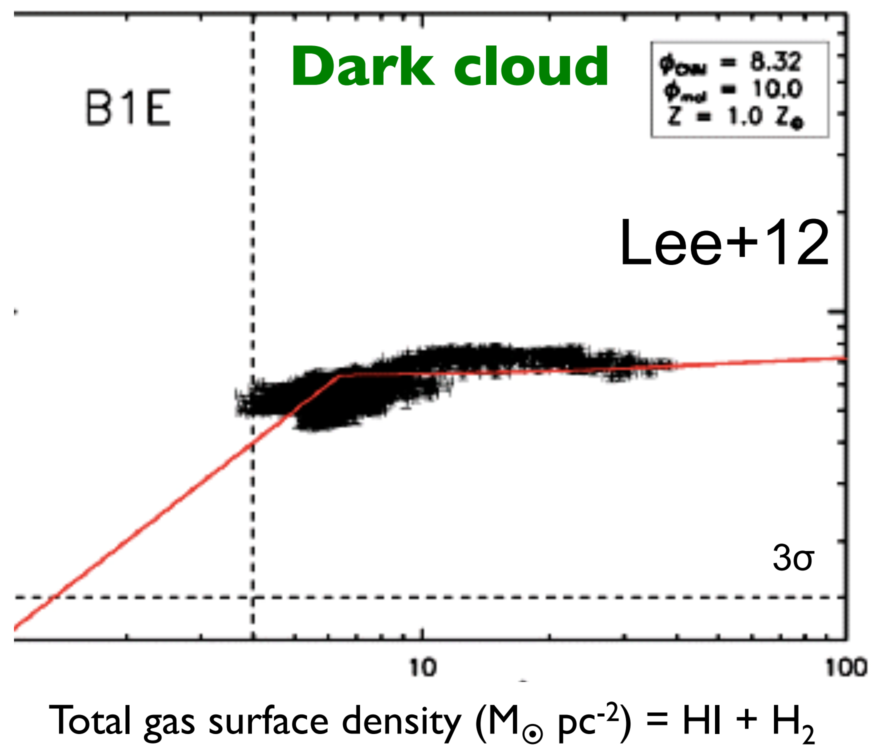
Do li je HI saturacija prisutna na visokoj rezoluciji? Yes.

HI saturates at 6-8 $M_\odot pc^{-2}$ @0.4pc for both star-forming and dark clouds.

ISRF of IC348 = ~2 ISRF of B1E
($ISRF \sim T_{dust}^6$)

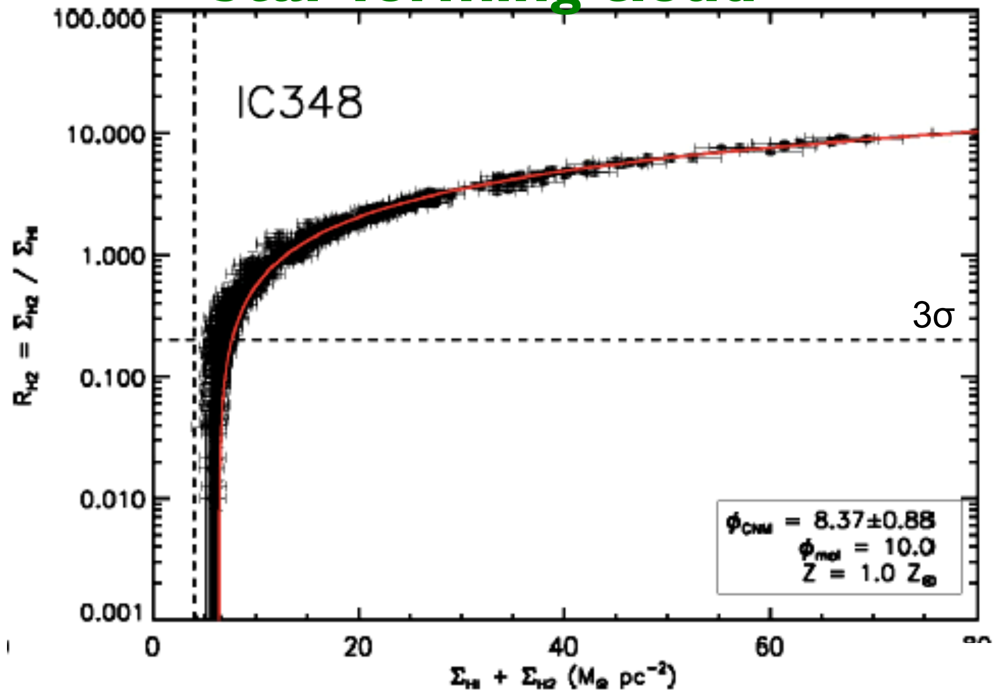






HI-H_2 tranzicija u Perseju:

Star forming cloud

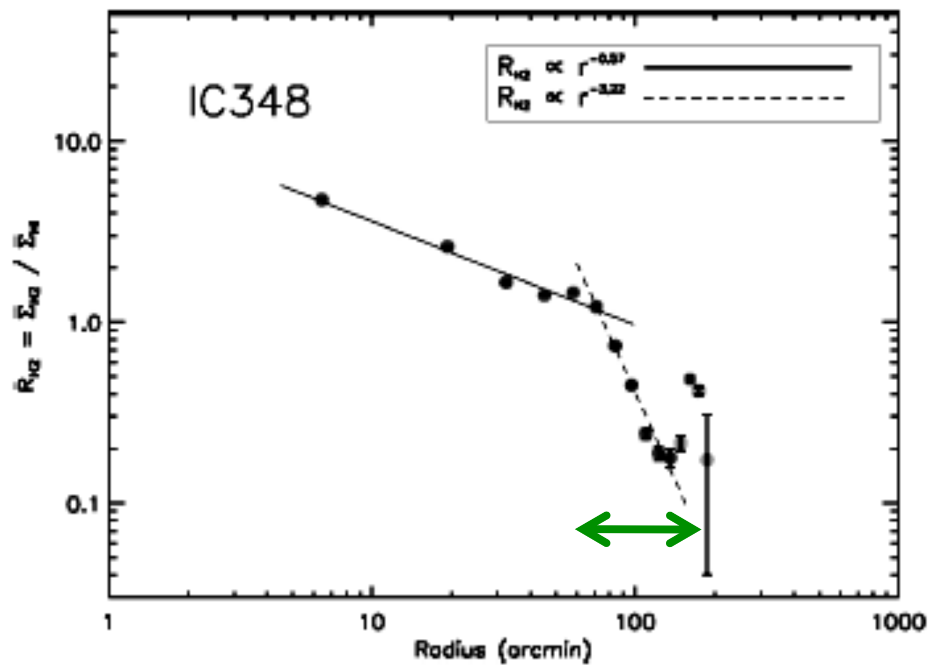


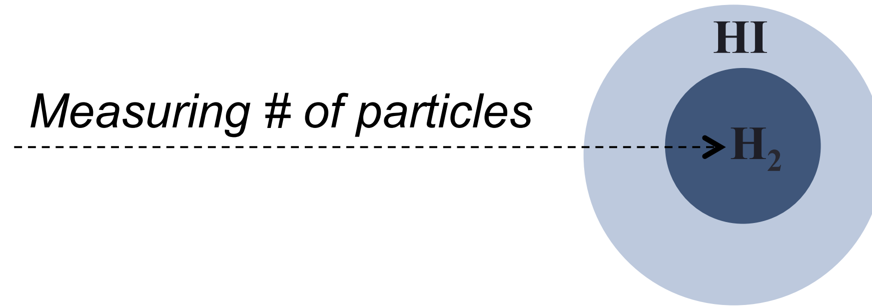
Assumed: Z = 1.0 $Z_\odot$
Fitted: ϕ_{CNM} = 7.0 ~ 8.0 or T_{CNM} = 60-75K
Dust-shielding and H_2 self-shielding equally important.

- Čim je linearna gustina dovoljna da zaštiti H_2, kolicina H_2 naglo raste

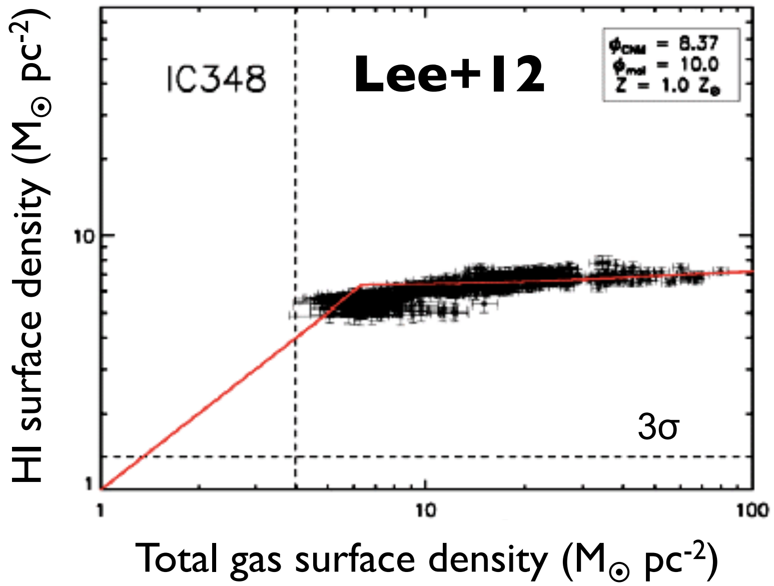
- H_2 se prostire ~20 pc od CO centra. → Čisto HI omotač ima radijus >20 pc.

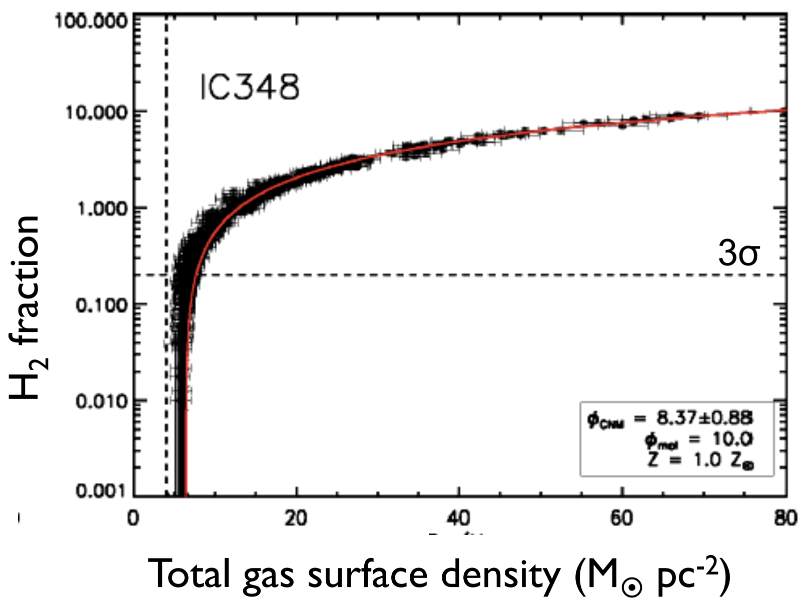
- Debljina regiona gde H_2 fraction raste od 0.1 do 0.25): 3-5 pc << velicine oblaka
→ **HI + čestice prašine važni za H_2!**

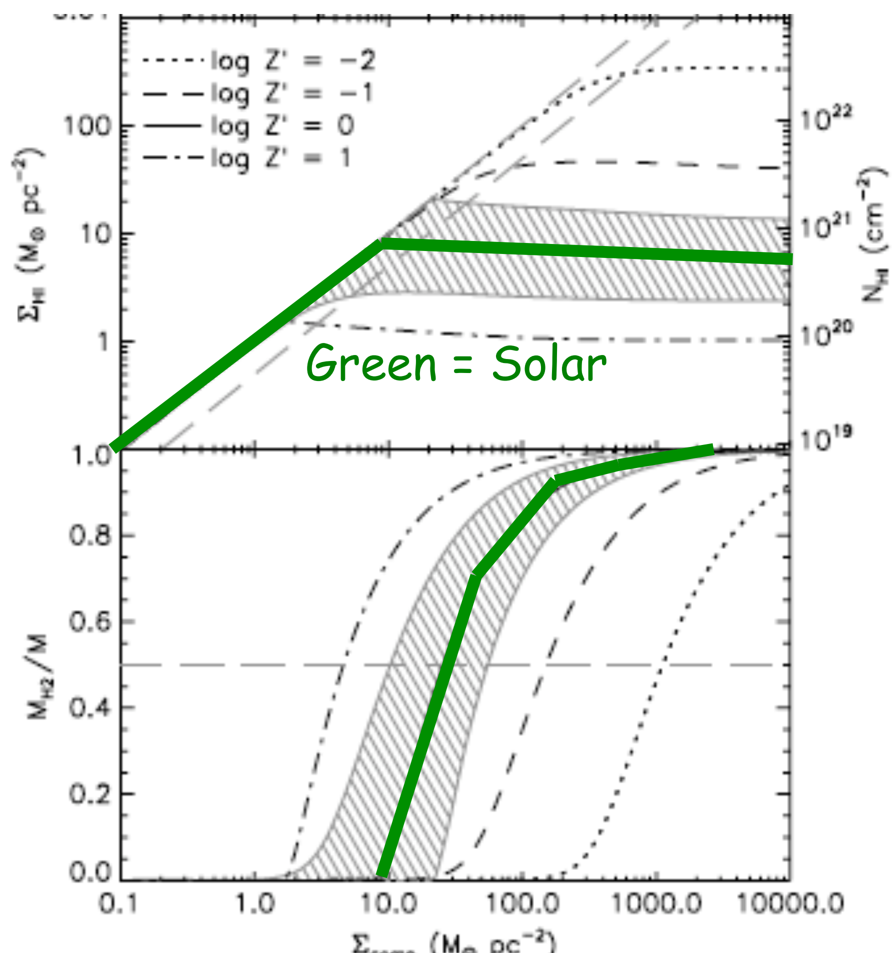




HI Shielding predicts H_2 abundance.

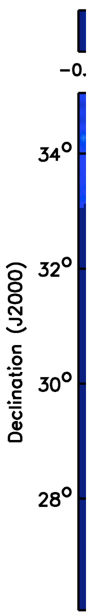


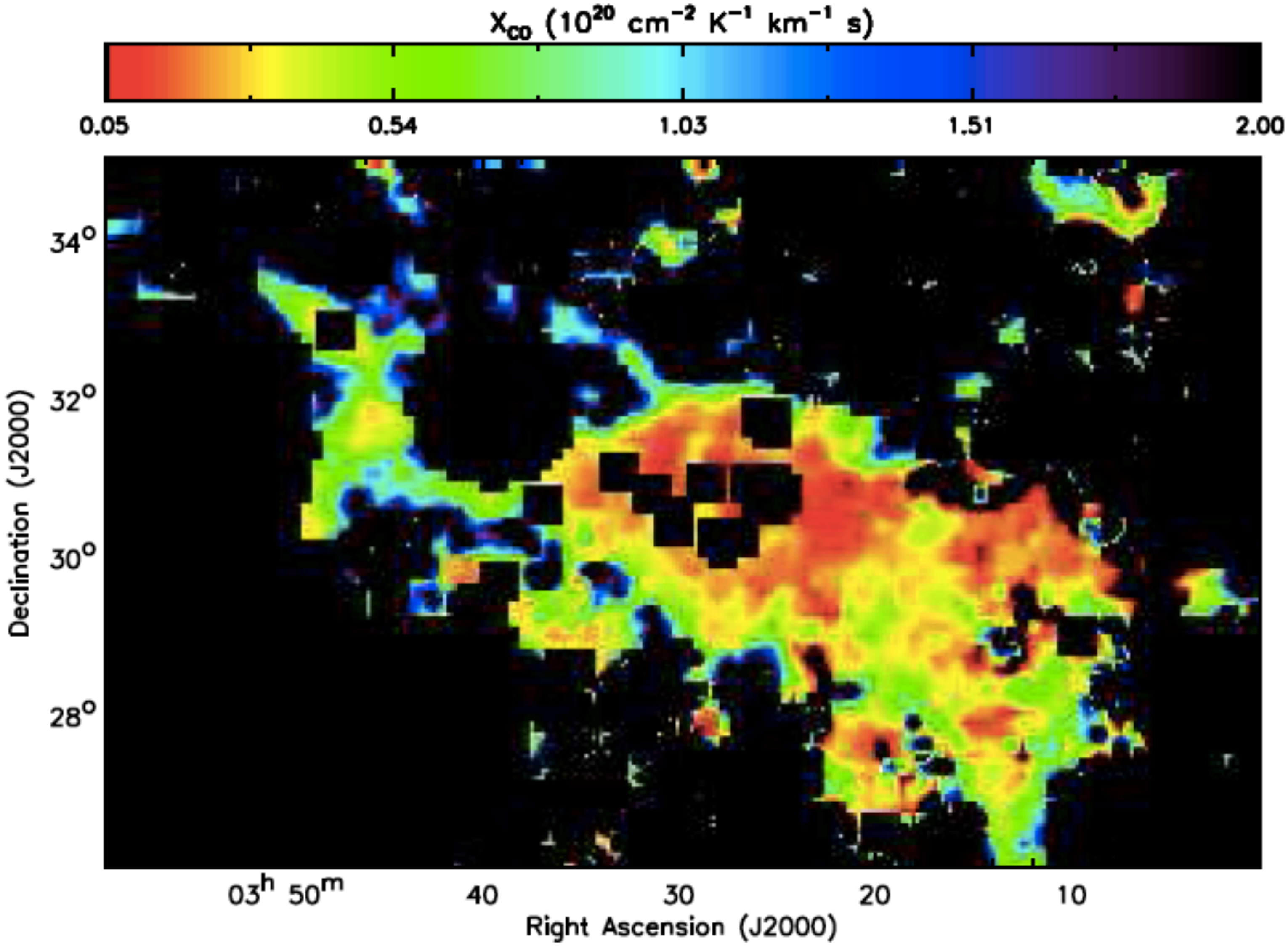


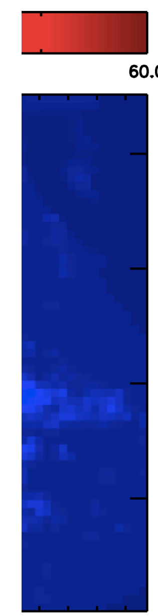


Krumholz et al. (2008, 2009)
Spitzer & Jenkins 75; Ostriker+10

Da li je HI vazan za formiranje CO?

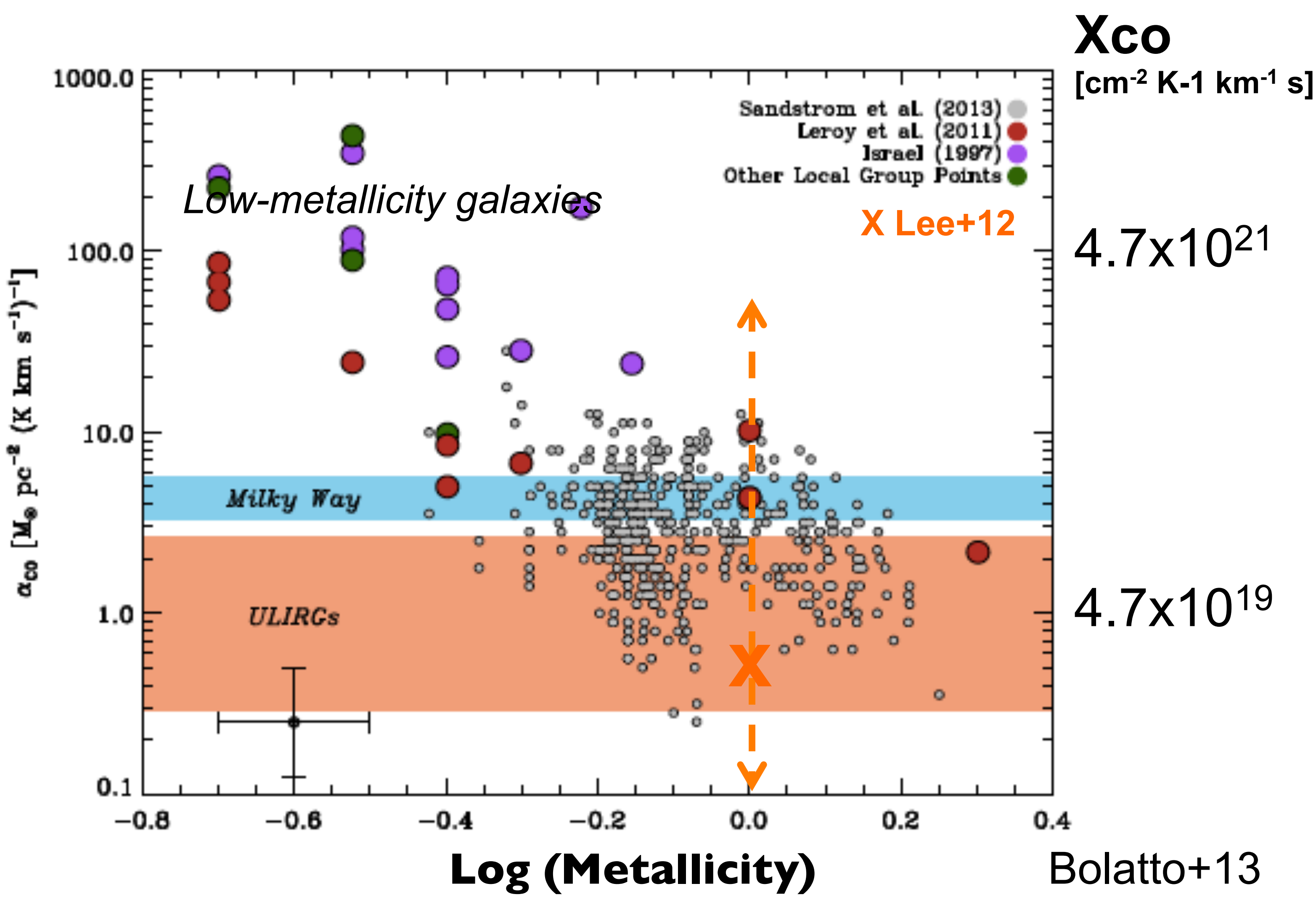






Lee, SS+13 **Median $X_{CO} = 3 \times 10^{19} \sim \Sigma\, N(H_2)/\Sigma\, I_{CO}$**

Persejev Xco u kontekstu

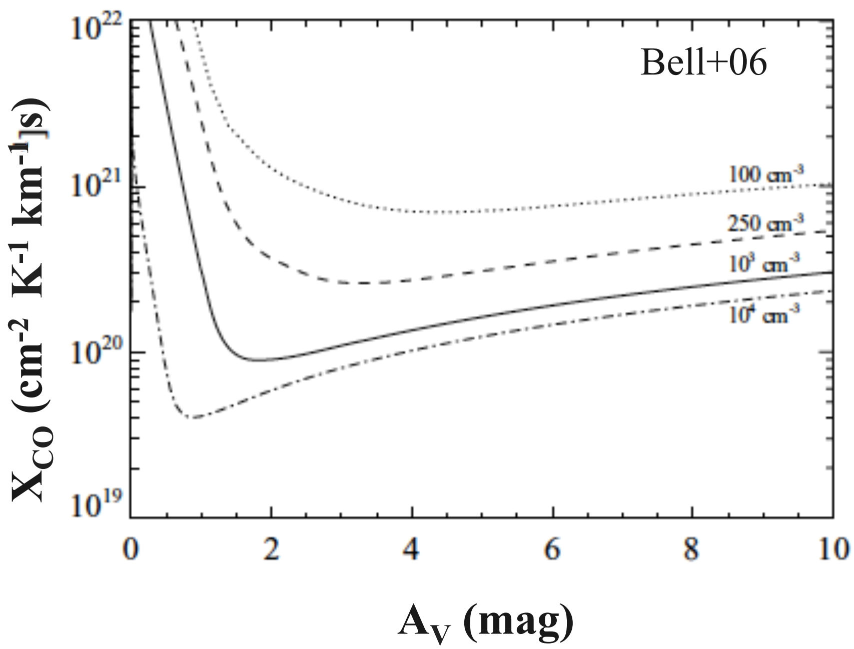


Persej: Xco u molekularnim oblacima zavisi od lokanih medjuzvezdanih uslova

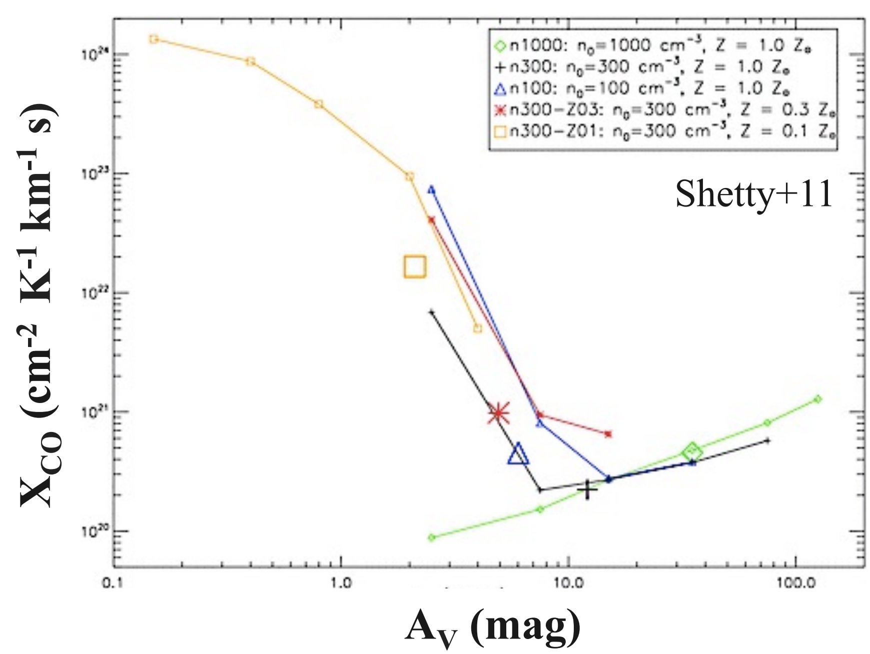
Xco = $N(H_2)$ / I_{CO} i “HI halos”?

- Theory $\boxed{\text{Xco} = F\ (n, G, Z, \xi, \sigma_{CO}, \text{cloud age})}$
- Large degeneracy BUT Characteristic dependence on A_V

PDR model
“Steady state & Equilibrium”



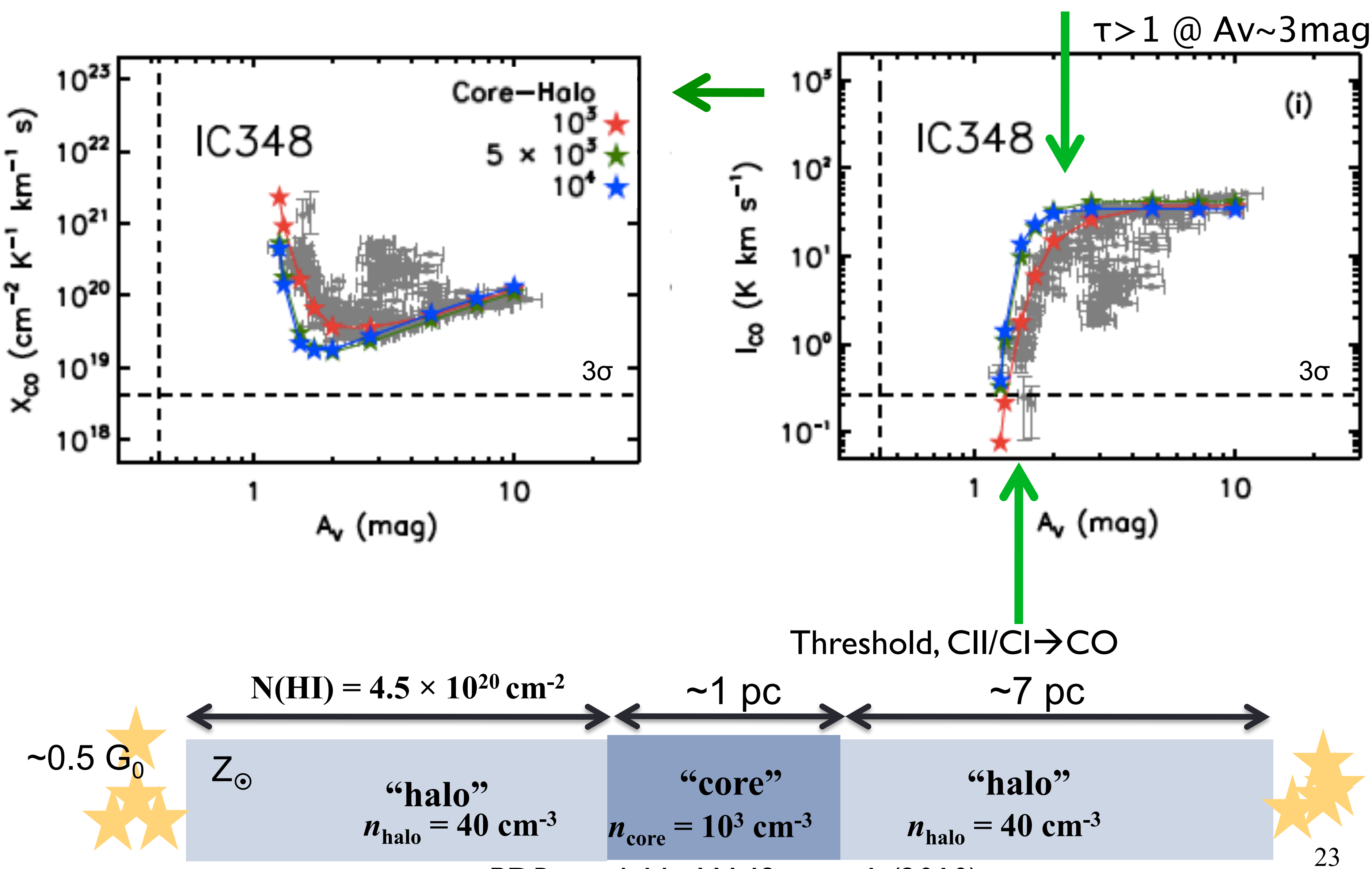
MHD model + Rad. Transfer
“Turbulent & Non-equilibrium”



For a chemically evolved Perseus
(age ~10 Myrs), model results should converge.

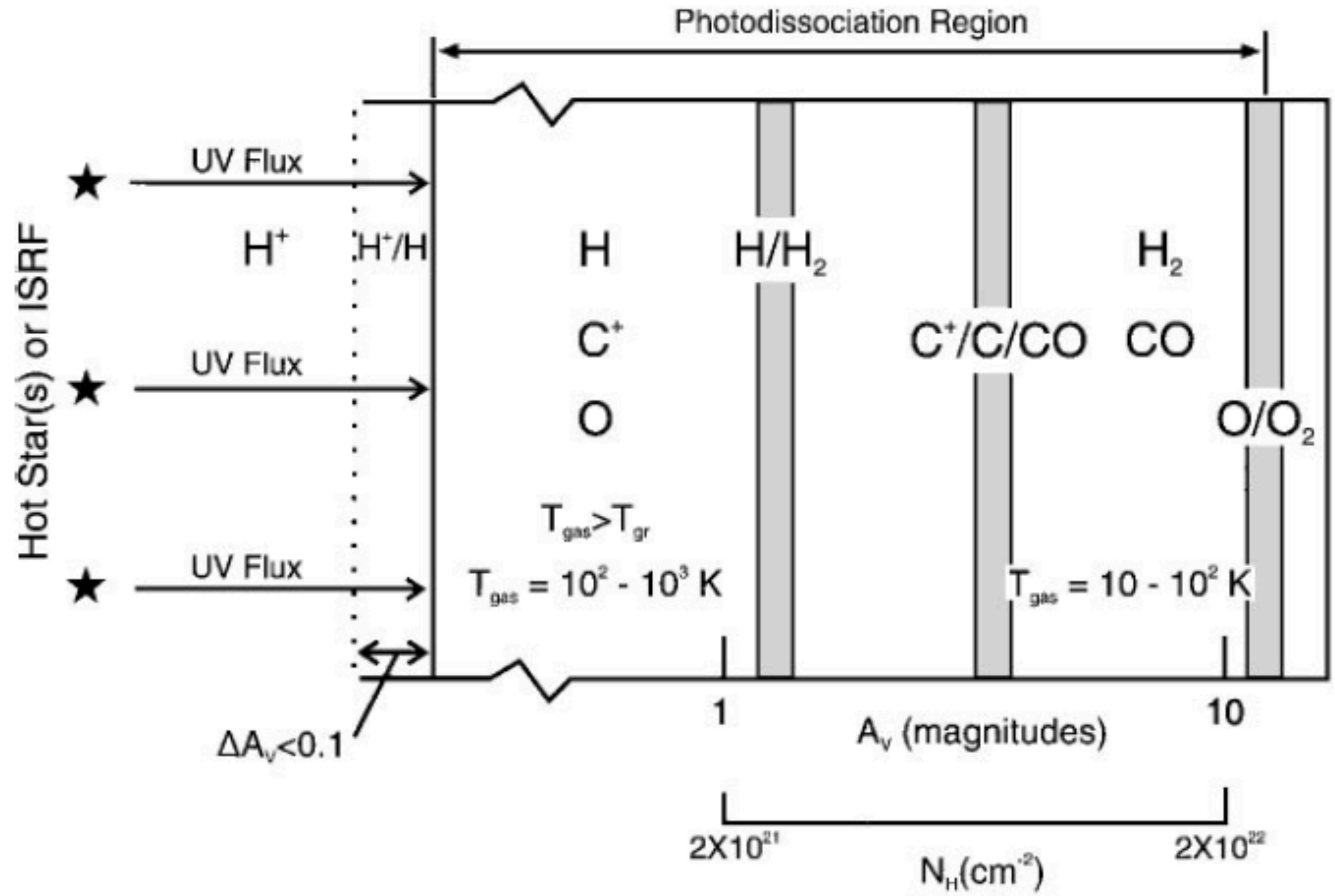
Glover & Mac Low11; Feldmann+12

X_{co} variations: a factor of ~80 over ~7pc



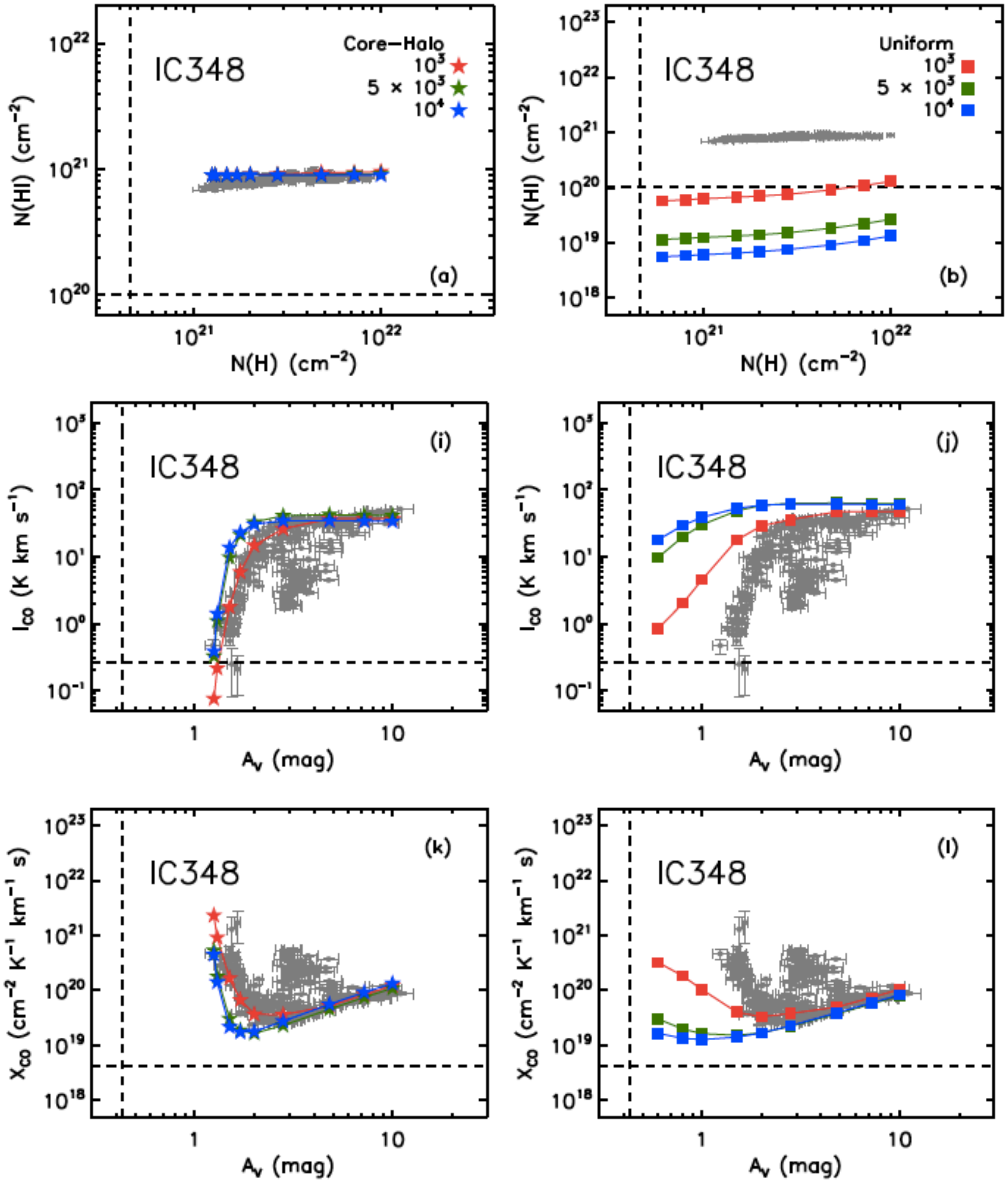
PDR model by Wolfire et al. (2010)

PDR: Photodissociation region - Analytical Modelling



- Transfer zracenja kroz paralelne zone i balans formiranja i raspadanja molecula
- 1D geometries: (e.g., van Dishoeck & Black 1986; Draine & Bertoldi 1996).
- Higher geometries: Only numerically studied (e.g., Spaans & Neufeld 1997).

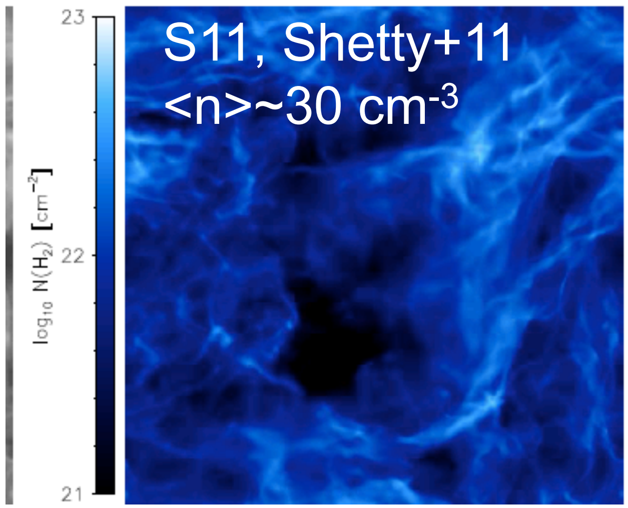
Core-halo model

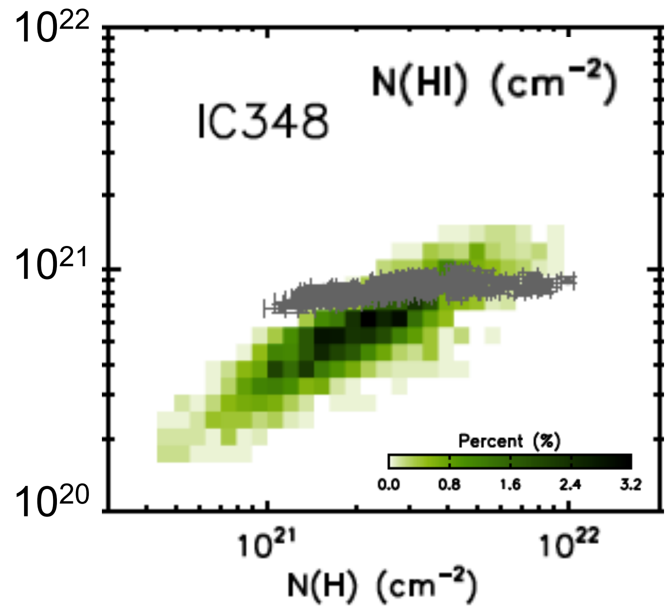


Uniform (just core) density model

Zastita molekula od strane cestica prasine u atomskim omotacima molekularnih oblaka je neophodna za: N(HI), I_{CO}, and X_{CO}.

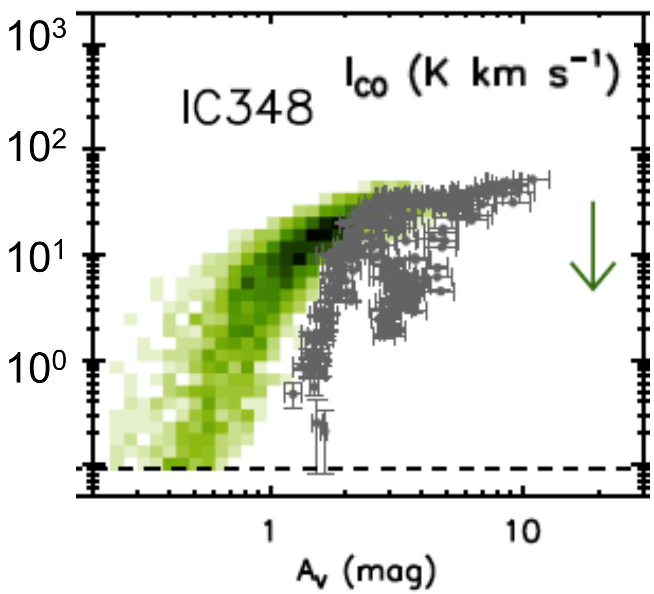
Poredjenje sa najnovijim MHD modelima

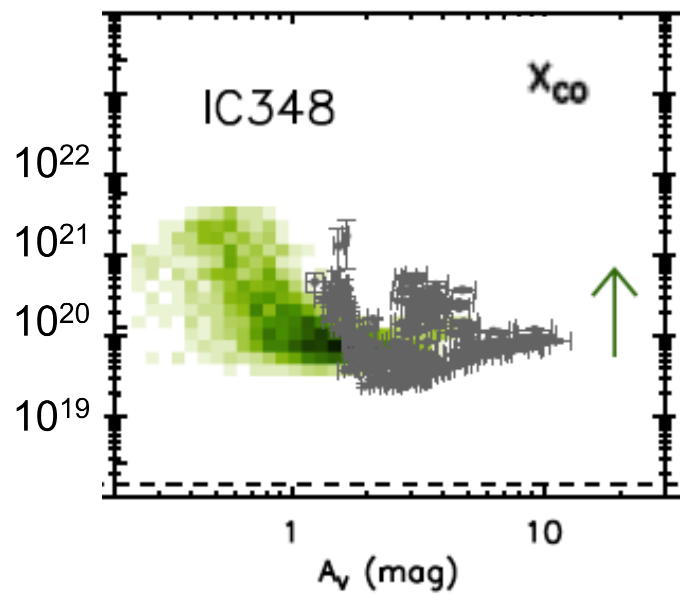




Qualitatively ok.

Discrepancies:
- N(HI) – turb. mixing?
- Shallow increase of I_{CO}
- Larger scatter
- Smaller Δv (CO)





Very different HI-H_2-CO geometry relative to PDR
→ *geometry not very important, just shielding?*

Zaključak:

- U Perseju zastita molekula od strane cestica prasine u HI omotacima molekularnih oblaka neophodna da objasni:

  N(HI), N(H_2), CO i X_{CO} ("Spitzer shield").

  - Sledeci korak: Taurus, California, Orion

    (Elijah Bernstein-Cooper PhD)

- Da li je "CO-dark" H_2 hladan HI? Da li H_2 nastaje iz hladnog ili toplog HI?
- SKA & Pathfinders (e.g. GASKAP): testiranje u sredini sa mnogo manjom kolicinom metala.
- ALMA, ATCA: posmatranja difuznog molecularnog gasa u Magelanovim oblacima