The HI-to-H$_2$ Transition in a Turbulent Medium

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Turbulent ISM

Molecular (H$_2$) clouds

Star formation
What drives turbulence in molecular clouds?

HI-to-H$_2$ transition $\iff$ Turbulence
HI-to-\textsubscript{H}_2 transition layers

Red = molecular gas (HCO\textsuperscript{+} J=3-2)

Green/Blue= ionized gas ([SII] 6731 Å, [OI] 6300 Å)
HI-to-H$_2$ transition layers

- H$_2$ forms on dust grains
- H$_2$ destroyed by UV (11.2-13.6 ev)
- UV absorbed by
  - dust
  - H$_2$ lines (self-shielding)
HI-to-H$_2$: the effect of Turbulence

- H$_2$ forms on dust grains
- H$_2$ destroyed by UV (11.2-13.6 ev)
- UV absorbed by dust
- UV absorbed by H$_2$ lines (self-shielding)

- supersonic turbulence $\rightarrow$ density fluctuations
  $\rightarrow$ variations in the H$_2$ abundance
  $\rightarrow$ variations in H$_2$ shielding
  $\rightarrow$ variations in the HI column density
HI-to-H₂: the effect of Turbulence

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- H₂ destroyed by UV (11.2-13.6 ev)
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- supersonic turbulence → density fluctuations
  → variations in the H₂ abundance
  → variations in H₂ shielding
  → variations in the HI column density
Model

(A) Numerical Simulations

- MHD simulations ($\mathcal{M}_S$, $\mathcal{M}_A$) $\rightarrow$ density structure
  - $512^3$ grid
  - Continuous driving, $L_{\text{drive}} = 0.5 \ L_{\text{box}}$

- Solve HI/H$_2$ equilibrium equations (post-process)

(B) Analytic Approximation

- Analytic formula for the HI column density PDF
Results: MHD simulations + HI-to-H$_2$

Subsonic $\mathcal{M}_s=0.5$

Supersonic $\mathcal{M}_s=4.5$

Bialy, Burkhart & Sternberg (2017)
Results: MHD simulations + HI-to-H$_2$

- Small scale-driving: $L_{\text{drive}}/L_{\text{HI}} \ll 1$
- Large scale-driving: $L_{\text{drive}}/L_{\text{HI}} > 1$

HI mass surface density

- Subsonic: $M_s = 0.5$
- Supersonic: $M_s = 4.5$

Bialy, Burkhart & Sternberg (2017)
MHD simulations + HI-to-H$_2$

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Bialy, Burkhart & Sternberg (2017)
Application to observations

*The Perseus molecular cloud - a nearby lab*
Application to observations

*The Perseus molecular cloud - a nearby lab*

- 21 cm (GALFA survey)
  \[ \Rightarrow \text{HI map for Perseus (Lee+15)} \]
Application to observations

*21 cm (GALFA survey)*

$\implies$ **HI** map for Perseus (Lee+15)

$\implies$ The **HI** PDF is very narrow

\[
\frac{\sigma_{N_{HI}}}{\langle N_{HI} \rangle} = 0.13
\]

(Burkhart+15)

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(Burkhart+15)

Model+observations suggest:

$M_s > 1$ and $L_{\text{drive}} \ll L_{\text{cloud}}$

OR

$M_s < 1$ and $L_{\text{drive}} \approx L_{\text{cloud}}$
Application to observations

The Perseus molecular cloud - a nearby lab

- 21 cm (GALFA survey)
  $\Rightarrow$ HI map for Perseus (Lee+15)
  $\Rightarrow$ The HI PDF is very narrow
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1-8 pc turbulence driving

- $^{12}\text{CO}^{13}\text{CO}$ observations suggest that protostellar outflows & winds account for the turbulence in Perseus (Arce+11)

21cm absorption observations: $M_s \sim 5$
Summary

• We modeled the HI/H₂ transition in a turbulent medium

• MHD simulations + Analytic formula for the HI PDF
  (a) Mach number
  (b) Driving scale

• HI observations (21 cm) can constrain turbulence

• Challenges:
  - Background/foreground HI
  - Estimating \( M_s \)
  - Time-dependent theory