4:45 pm ~

Zoom in on Star Formation, 2019.Jun.10 @ the Vouleftikon, Nafplio

Time Evolution of the Multiphase Interstellar Medium in Shocked Layers

(Kobayashi+ 2019 to be submitted)

Objects: The multiphase ISM
Methods: Hydro simulations
Goal: Formulate one-phase approximation

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Outline

✓ **Backgrounds**

- The multiphase interstellar medium (ISM)
- Sub-grid modeling
- **One-phase approximation with converging flows**

✓ **Physical properties of the multiphase ISM in shocked layer**

(Kobayashi+ 2019 to be submitted)

- Shock propagation
- Warm / Cold mass ratio
- **Effective EoS**
- Energy conversion to turbulence
- Convergence study, single shock propagation (if time allows)

✓ **Summary**

Backgrounds

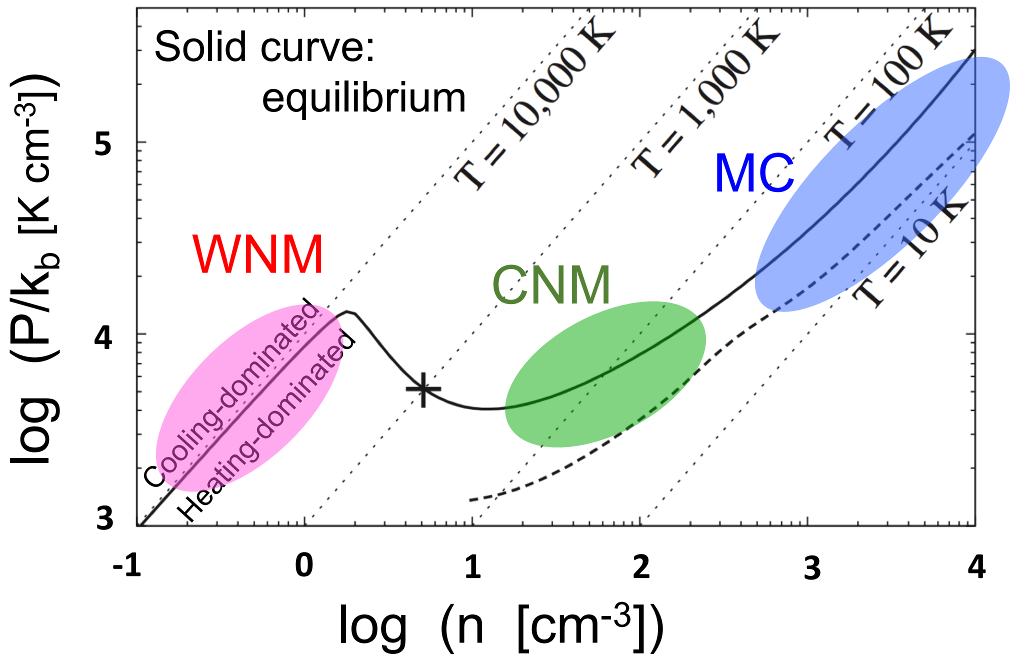
- ✓ The multiphase ISM
- ✓ Sub-grid modelling
- ✓ One-phase approximation
  with converging flows

Multiphase ISM @ present-day

Thermal equilibrium/instability

Heating: photo-electric
Cooling: Lyα, OI, CII, CO

Inoue & Inutsuka 2012



1) Warm Neutral Medium (WNM)

Most volume in the MW disk

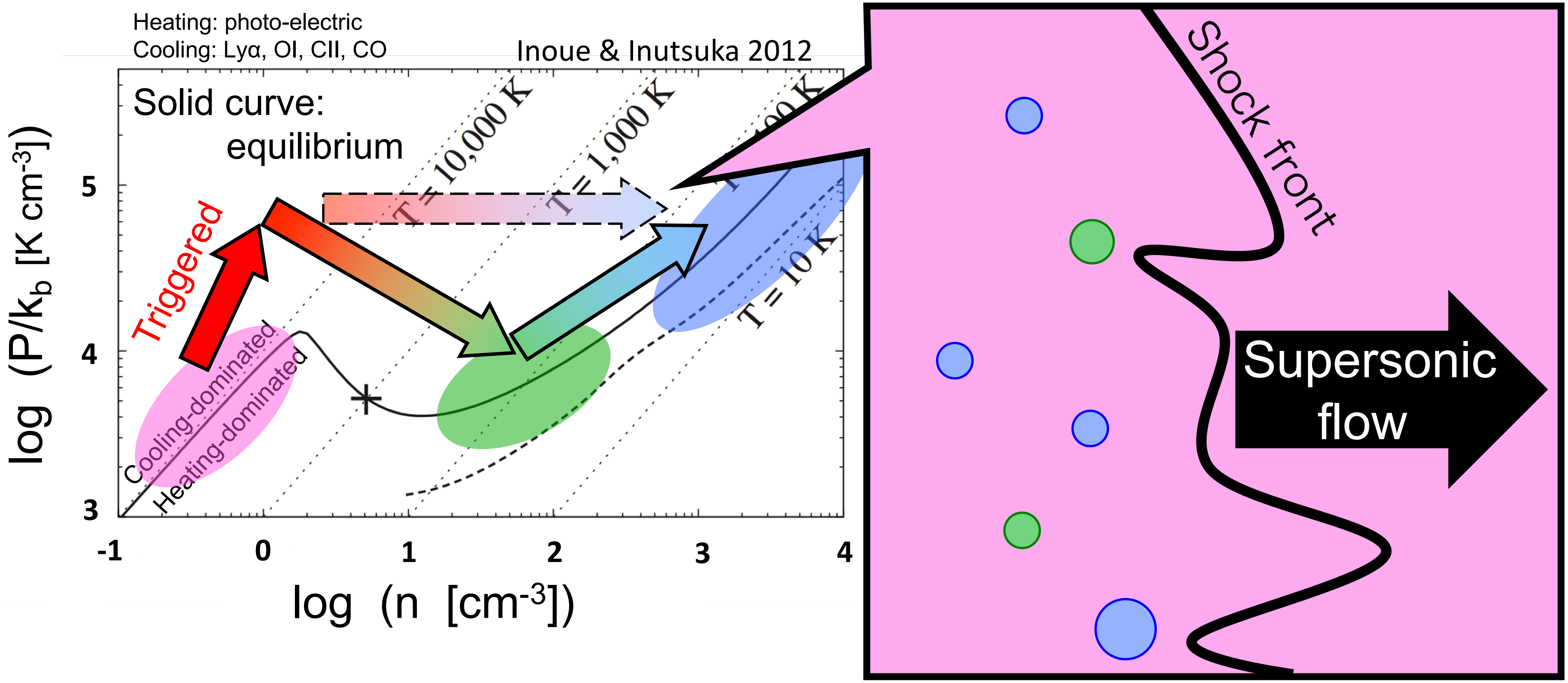
2) Cold Neutral Medium (CNM)

3) Molecular Gas (MC)

progenitor of stars

Multiphase ISM @ present-day

Thermal equilibrium/instability



⇨ External trigger (e.g., supersonic flow) is required to compress WNM efficiently and cool down to CNM & MC (phase transition).

Typical scale: diffusion/cooling balance $\leq$ **0.1 pc @ WNM-CNM**

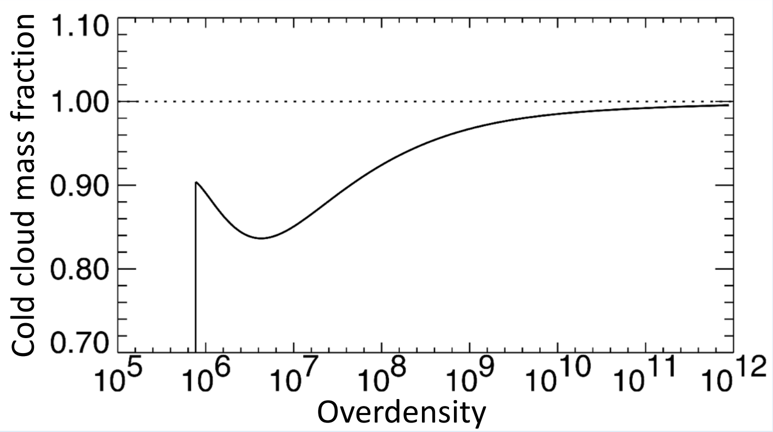
⇨ Large-scale simulations need a sub-grid modelling.

Sub-grid modelling

Feedback-driven model

(Quasi-)steady state, thermal + non-thermal:
McKee & Ostriker 1977, Yepes+ 1997,
Springel & Hernquist 2003, Marinacci+ 2019, *etc.*

Ex.) SPH: Springel & Hernquist 2003

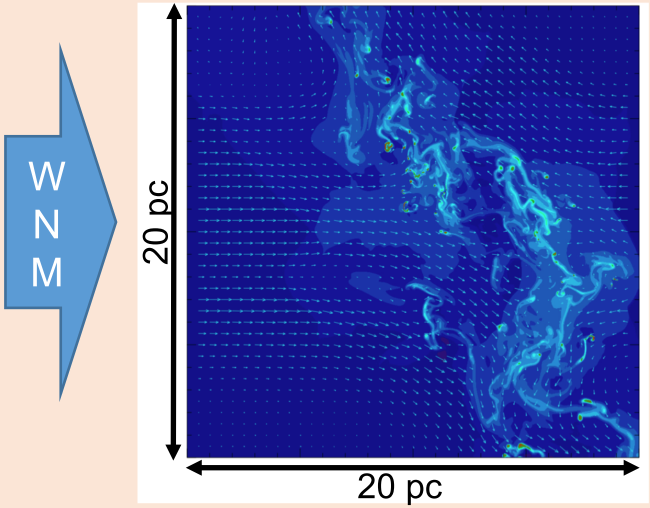


Converging flow simulations

Non-magnetized: Hennebelle & Perault 1999, Audit & Hennebelle 2005, Heitsch+ 2005, 2006, Vazqueqz-Semadeni+ 2006, 2007, *etc.*

Magnetized: Inoue & Inutsuka 2008, 2012, Hennebelle+ 2008, Vazquez-Semadeni+ 2011, Valdivia+ 2016, Iwasaki+ 2019, *etc.*

Ex.) 2D converging WNM flow: Audit & Hennebelle 2005



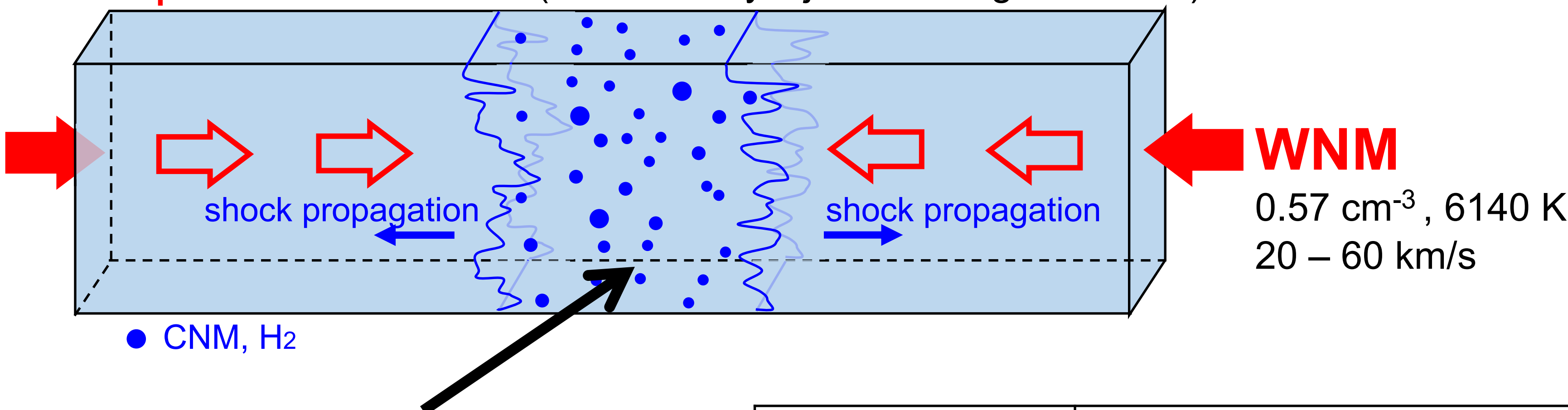
<u>Our simple question</u>

Formulate an approximate one-phase ISM with an effective EoS derived from converging flow simulations, ideally with its time-evolution?

Converging WNM flow

3D box (x,y,z = 80 pc, 10 pc, 10 pc) today only non-magnetized

supersonic HI flow (continuously injected along the x-axis)



One-phase approximation

$$P = K\rho^{\gamma}$$

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma+1)\mathcal{M}_1^2}{(\gamma-1)\mathcal{M}_1^2+2}$$

(1, 2: pre- and post-shock regions)

Effective index γ obtained from

ρ_2 (mean density in the post-shock region) and M_1(shock propagation speed)

Code	Inoue & Inutsuka 2008
Heating / Cooling	Photo-electric / Lyα, OI, CII
Conduction	H+H collision (Parker 1953)
Turbulent seed	Kolmogorov perturbation (Kolmogorov 1941)
Resolution	0.08pc (0.01 pc at highest)

Summary (toward global modelling)

✓Backgrounds: One-phase approximation

- The multiphase ISM and its sub-grid modelling
- One-phase modelling based on converging flow simulations

✓Results: Nearly isothermal evolution

- Warm:Cold mass ratio ~ 1:1
- Energy conversion rate into turbulence ~ 1 percent
- Field length by 8 cells is enough for one-phase approximation

✓Future Prospects:

- B-fields
- Single shock propagation (sandwiched by shock & contact discontinuity)