

1:20 pm ~

Physical Conditions of the Multiphase Interstellar Medium in Converging HI flow

(Kobayashi+ 2018b in progress)

Method: hydro simulation

Goal: model the multiphase ISM in galactic disks

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Team BISTRO-J
COMING
CHIMPS2

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Outline

- ✓ **Background (the multiphase ISM)**
 - ◆ Towards galactic-scale star-formation simulation along with the multiphase ISM
 - ◆ Converging HI flow to measure shock propagations
 - ◆ One-fluid approximation

- ✓ **Time Evolution of the Shock-Compressed Layer**
 - ◆ Initial conditions
 - ◆ Warm Gas Mass fraction
 - ◆ Effective gamma

- ✓ **Summary**

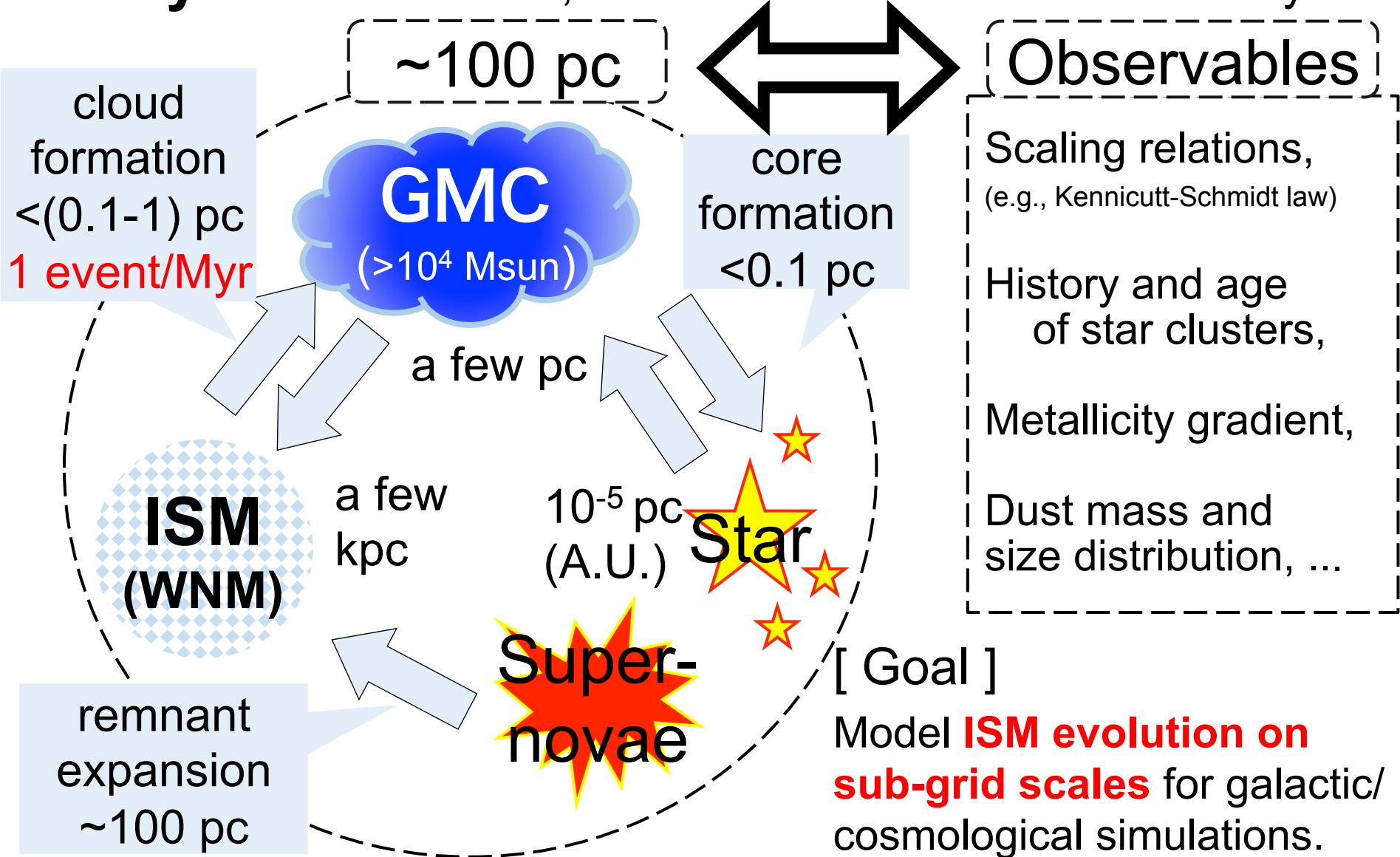
The Multiphase ISM

- ✓ Multi-scale processes and observables
- ✓ Phase transitions
- ✓ Converging H_I flow

Star Formation in Galaxies

(1pc = 3×10^{18} cm)

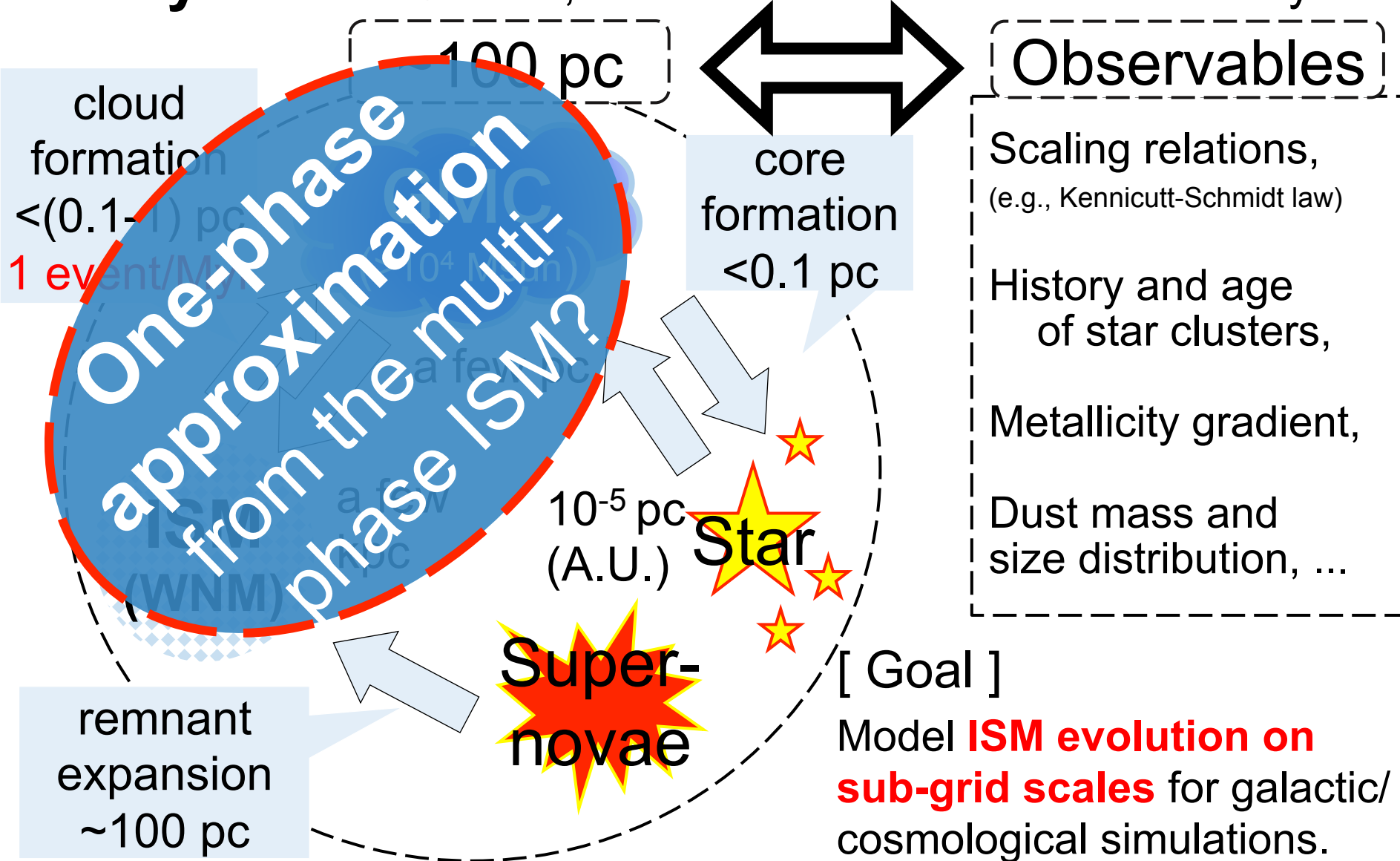
Always Multi-Scale, difficult to calculate all consistently



Star Formation in Galaxies

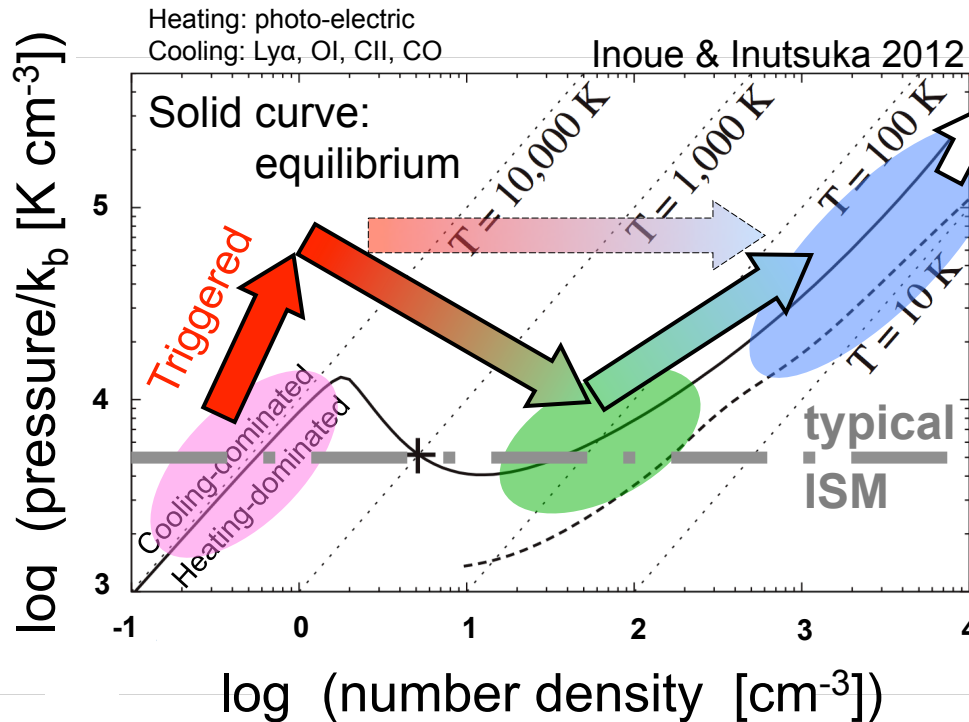
(1 pc = 3×10^{18} cm)

Always Multi-Scale, difficult to calculate all consistently



Multiphase ISM @ present-day

Thermal equilibrium/instability



1) Warm Neutral Medium (WNM)

warm HI, 10^{-2-0} cm $^{-3}$, 10^4 K

Most volume in the MW disk

2) Cold Neutral Medium (CNM)

cold HI, 10^{0-2} cm $^{-3}$, 10^{1-3} K

3) Molecular Gas (MC)

H $_2$ (mostly bright in ^{12}CO)

$>10^2$ cm $^{-3}$, $<10^1$ K, **progenitor of stars**

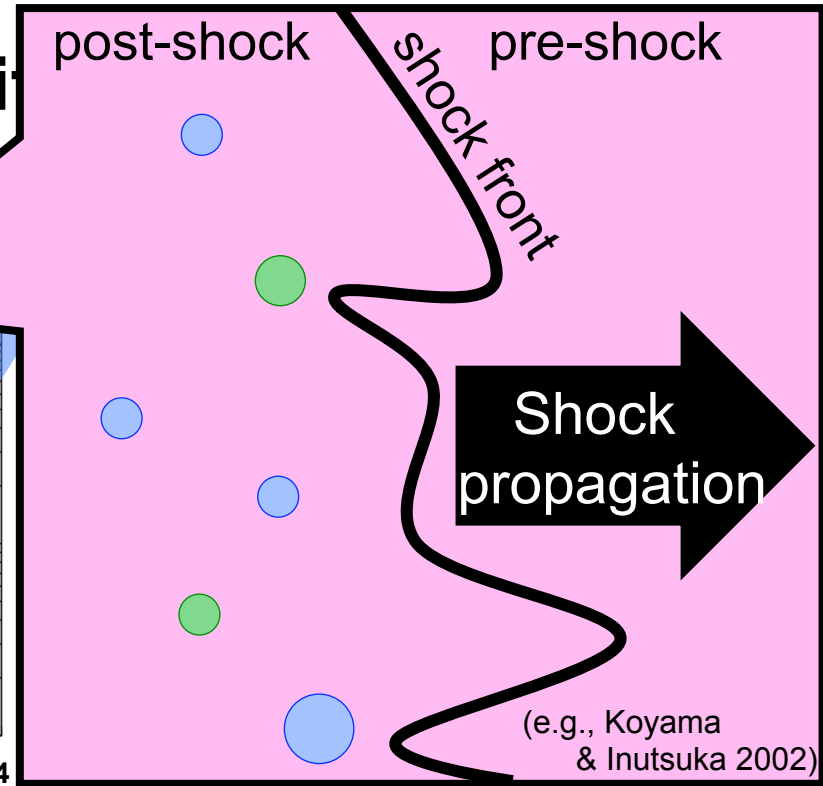
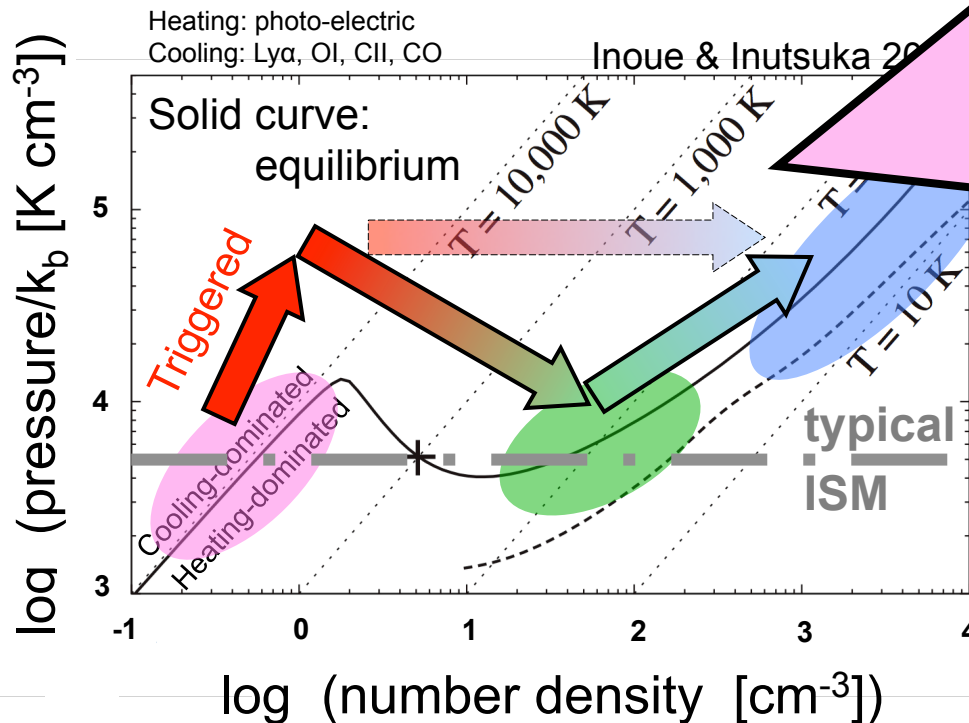
Thermally unstable; WNM self-gravity alone may not result in CNM/MC formation ...

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

Typical scale: sound speed x cooling time = **0.1-1 pc @ CNM-WNM**

Multiphase ISM @ present-day

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Shocks outgo beyond a simulation box...

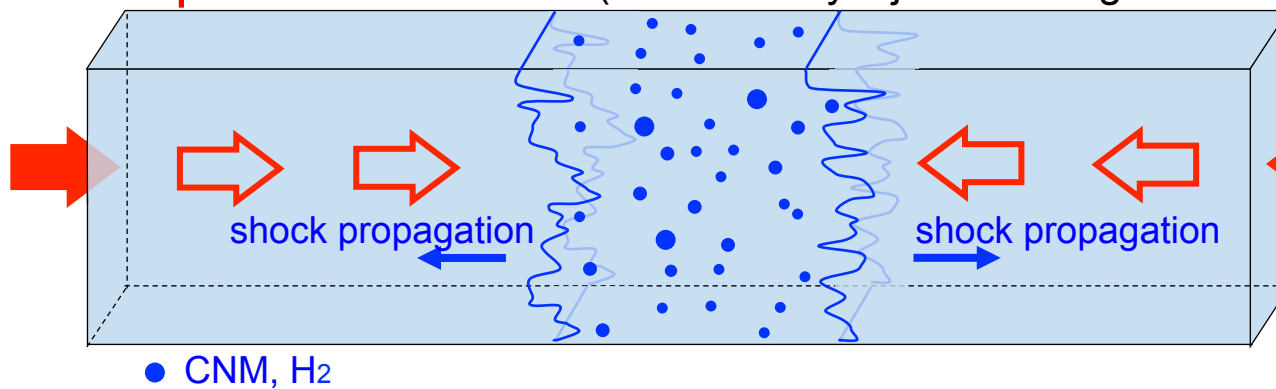
Let us calculate **converging HI flows instead** (, which has two shock fronts).

Converging HI flow

(c.f., Hennebelle & Perault 1999,
Audit & Hennebelle 2005, 2008, Heitsch 2005,
Vazquez-Semadeni 2006, 2007, etc.)

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

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



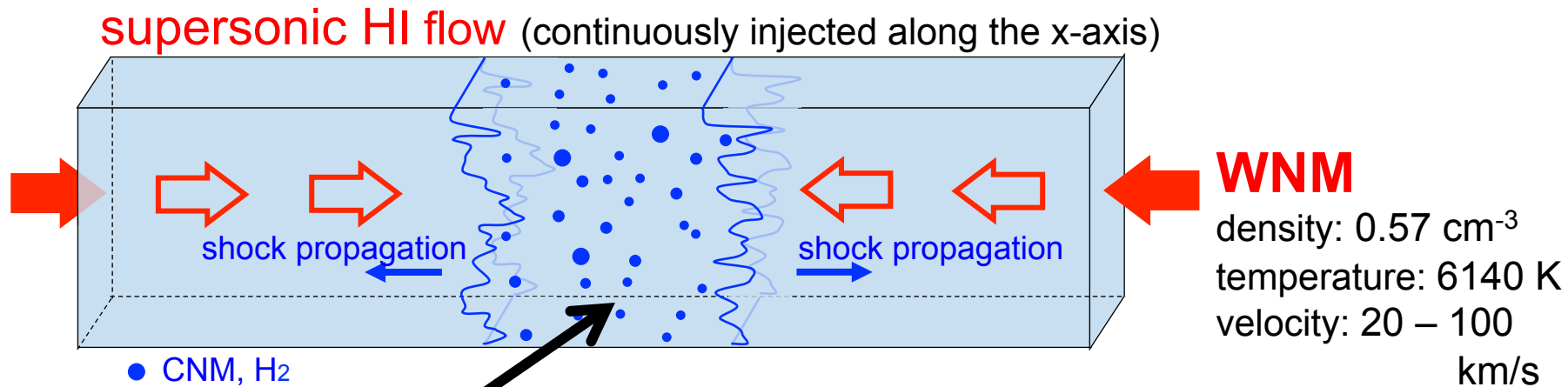
WNM

density: 0.57 cm^{-3}
temperature: 6140 K
velocity: 20 – 100
km/s

Converging HI flow

(c.f., Hennebelle & Perault 1999,
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Vazquez-Semadeni 2006, 2007, etc.)

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



[goal 0-1] long-term evolution @ >10Myr

[goal 0-2] fast-flow evolution @ > 20km/s

[goal 1] mass partition in WNM/CNM

[goal 2] one-phase approximation

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

$$\frac{\rho_2}{\rho_1} = \frac{(\gamma + 1) \mathcal{M}_1^2}{(\gamma - 1) \mathcal{M}_1^2 + 2} \quad (1, 2: \text{pre- and post-shock regions})$$

→ **Effective γ gamma** from ρ_2 (mean density in the post-shock region / WNM fraction) and \mathcal{M}_1 (shock propagation speed)

code: Inoue & Inutsuka 2008 hydro part

Finite Volume method with Eulerian remapping
(Van Leer 1979)

Heating/Cooling: photo-electric, Ly α , OI, CII
(Koyama & Inutsuka 2002)

Thermal conduction: H+H collision (Parker 1953)

Kolmogorov(-like) perturbation (Kolmogorov 1941)

Meshes: 1024 x 128 x 128 (= 0.08 pc/mesh)

Time Evolution of the Shock-Compressed Layer

- ✓ Initial condition
- ✓ Time-evolution
- ✓ WNM mass fraction
- ✓ Effective gamma

Initial Condition

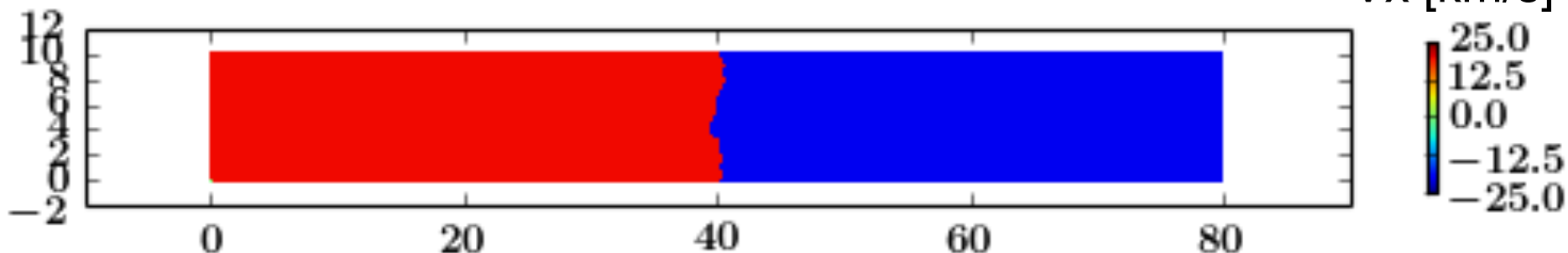
Perturbed shock-front (no perturbation input afterwards)

Kolmogorov-like perturbation (Kolmogorov 1941)
so that two flows collide at $x(y,z) = \text{box-center} + dx(y,z)$

$$\delta x = \sum_{k_y, k_z}^{k_{y,\max}=10, k_{z,\max}=10} P(k_y, k_z) \sin(k_y y + k_z z + \alpha_{k_y, k_z})$$

$$P(k_y, k_z) = A(k_y, k_z) |k|^{-11/6} \quad \text{(Amplitude is set so that its mean becomes 1pc.)}$$

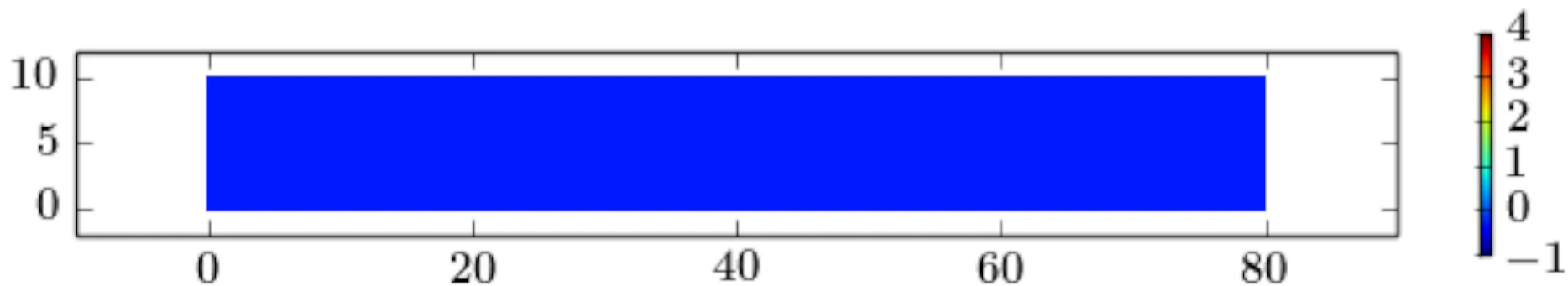
Velocity map @ t=0 (yz-plane; in case of two 20km/s flows) color:



Time-Evolution

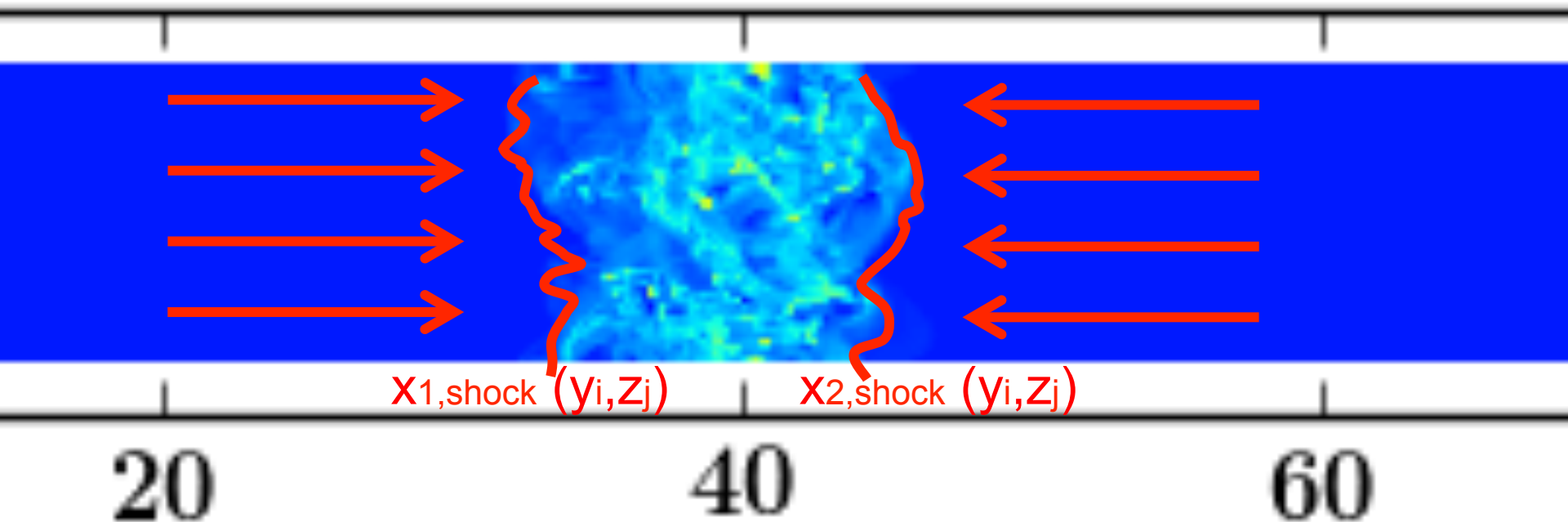
Density slice

color:
 $\log_{10}(n[\text{/cc}])$



Shock Capturing

Trace **temperature/entropy jump**



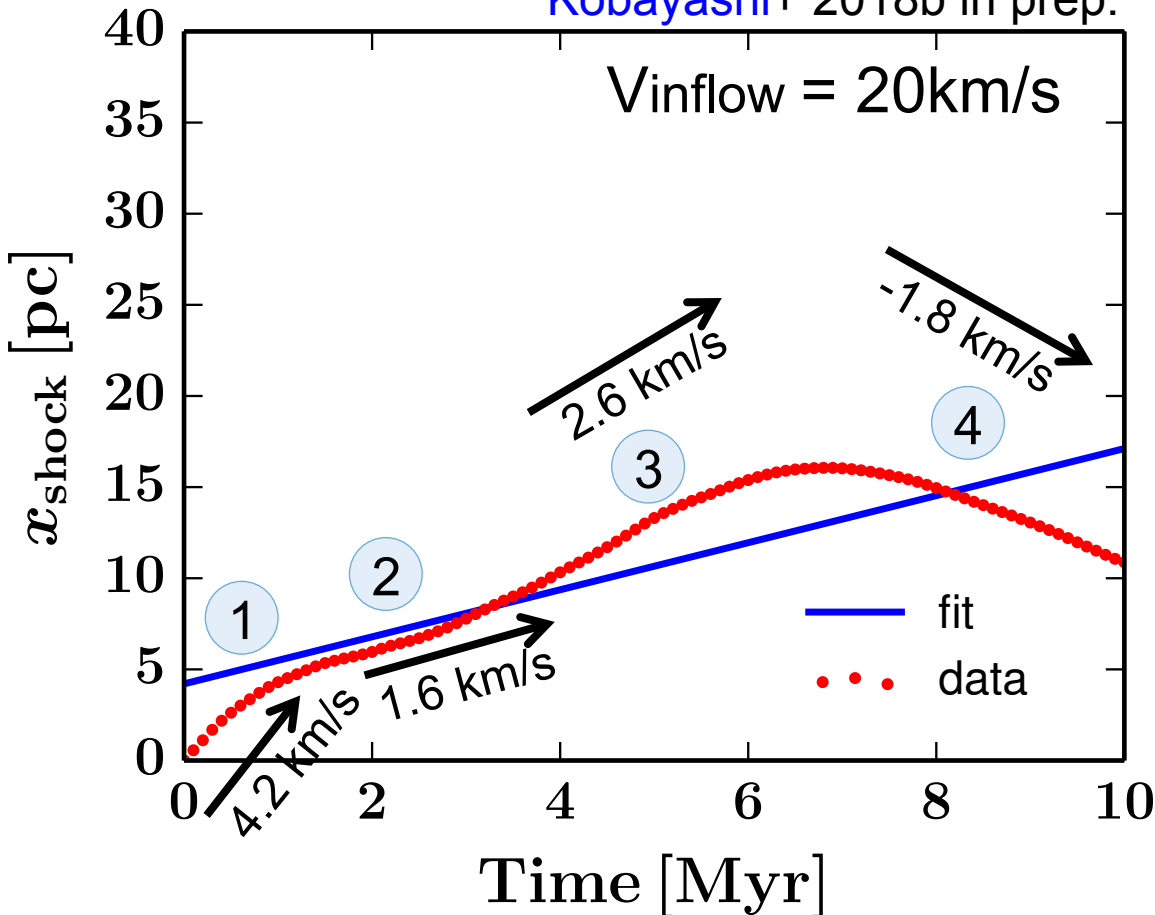
Averaged shock front position

$$x_{shock} = \frac{\sum_{i,j}^{128,128} (x_{2,shock} - x_{1,shock})}{2 \times 128 \times 128}$$

Long-term Shock Propagation

Shocks propagate outwards with some **oscillation**
 = mass fraction and γ_{eff} evolve in time accordingly

Kobayashi+ 2018b in prep.



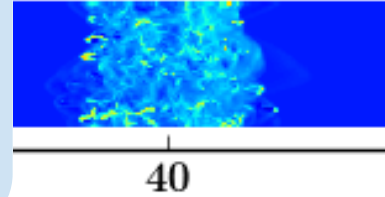
- ① almost adiabatic
 ($\gamma_{\text{eff}} \sim 1.2$, $\rho_2/\rho_1 = 5.7$)
- ② steady expansion
 (~ 0.93 , 8.8)
- ③ mostly isothermal
 (~ 0.96 , 9.0)
- ④ overall shrink
 ($\sim 0.68 \ll 1$, 19.9)

Summary

✓ Background: model the multiphase ISM

- ◆ Star formation processes in galaxies
- ◆ One-phase approximation from the multiphase ISM
- ◆ Converging HI flow and γ_{eff}

compressed
layer



✓ Time Evolution of Shock-compressed layer

- ◆ After 4 Myr, **volume** is occupied by **WNM** whereas **mass** by **CNM**
- ◆ Typical mass fraction between **warm / cold gas** $\sim 1:1$.
- ◆ Sub-grid ISM model (especially star forming cold gas) has to **evolve in time based on its latest shock experience**.

✓ Prospects

- ◆ Perturbation (in large-scale/time)
- ◆ Oblique converging flow
- ◆ Fitting formula: $f(V_{\text{inflow}}, t)$

