1:30pm~

Physical Properties of the Multiphase Interstellar Medium

(Kobayashi+ 2018b in progress)

Method: hydro simulation
Goal: model the multiphase ISM in galactic disks

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SKA-JP
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Team BISTRO-J
COMING
CHIMPS2

Filament Paradigm, 2018.Nov.9 @ Nagoya University, JAPAN

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Kengo Tomida, Kazunari Iwasaki (Osaka Univ.)

Outline

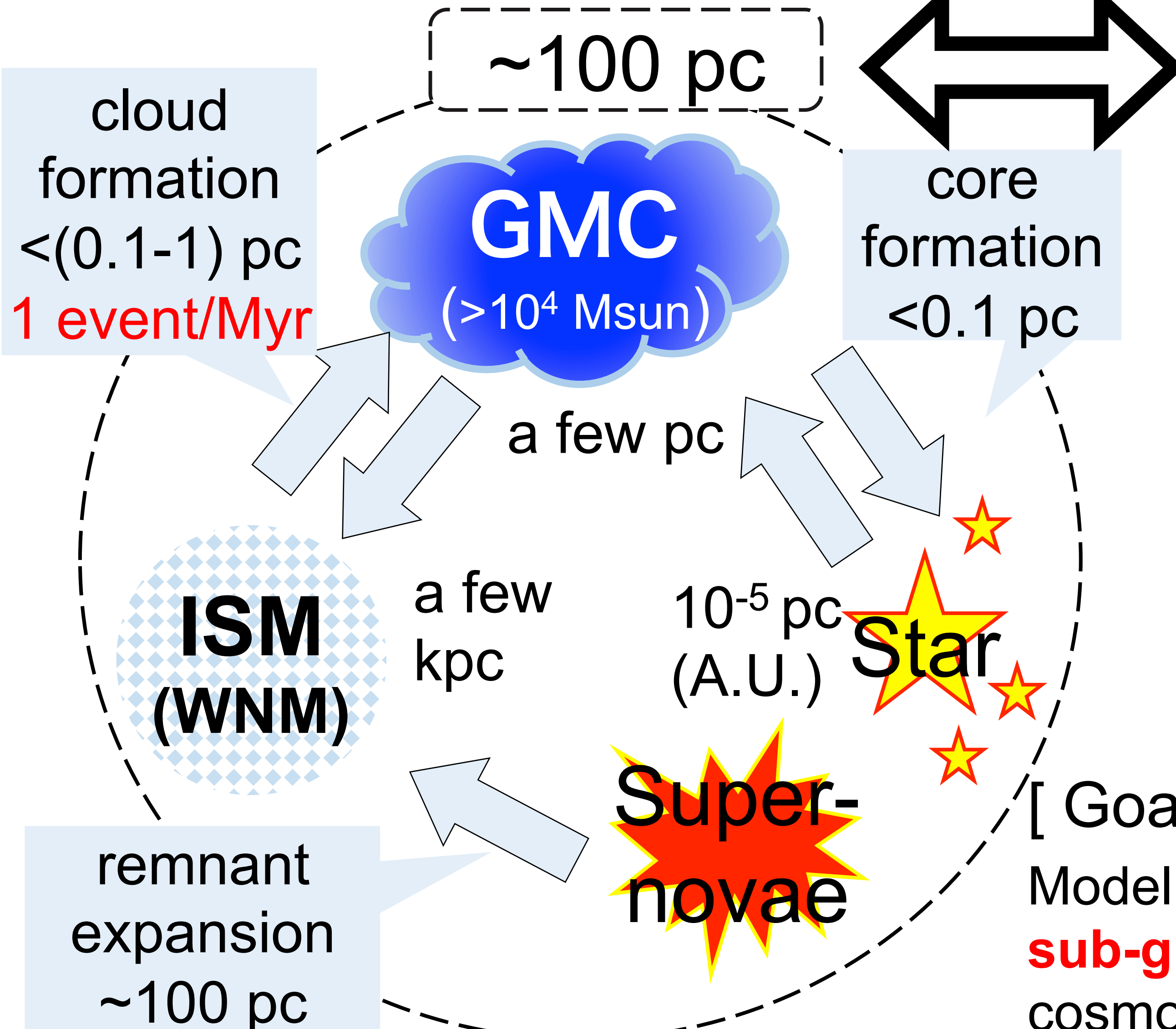
- ✓ **Background (the multiphase ISM)**
  - Towards galactic-scale star-formation simulation along with the multiphase ISM
  - Converging HI flow to measure shock propagations
  - One-fluid approximation
- ✓ **Time Evolution of the Shock-Compressed Layer**
  - Initial conditions
  - Warm Gas Mass fraction
  - Effective gamma
- ✓ **Summary**

The Multiphase ISM

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

Star Formation in Galaxies

Always Multi-Scale, difficult to calculate all consistently



Observables

- Scaling relations,
  (e.g., Kennicutt-Schmidt law)
- History and age of star clusters,
- Metallicity gradient,
- Dust mass and size distribution, ...

[Goal]

Model **ISM evolution on sub-grid scales** for galactic/ cosmological simulations.

Star Formation in Galaxies

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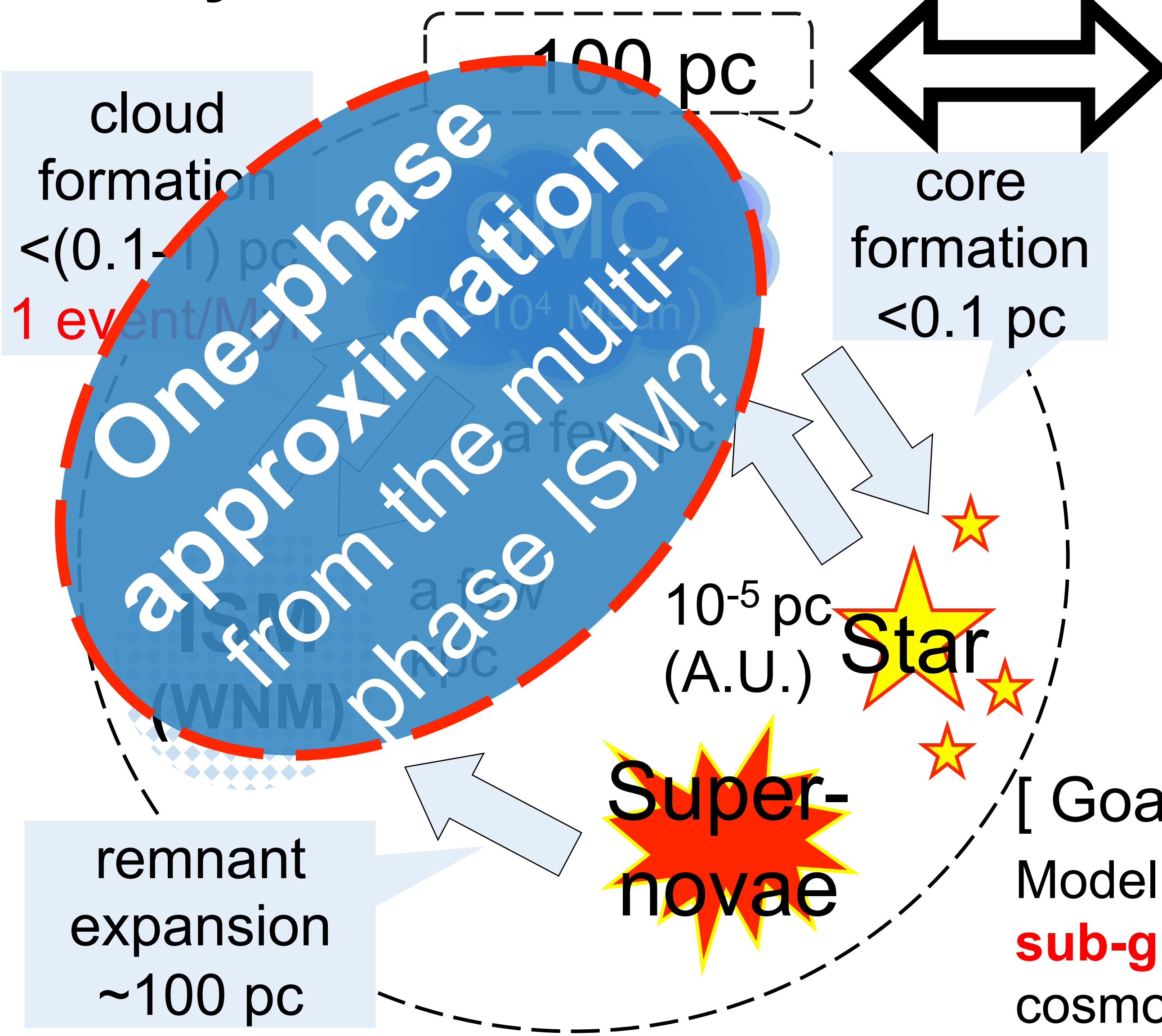

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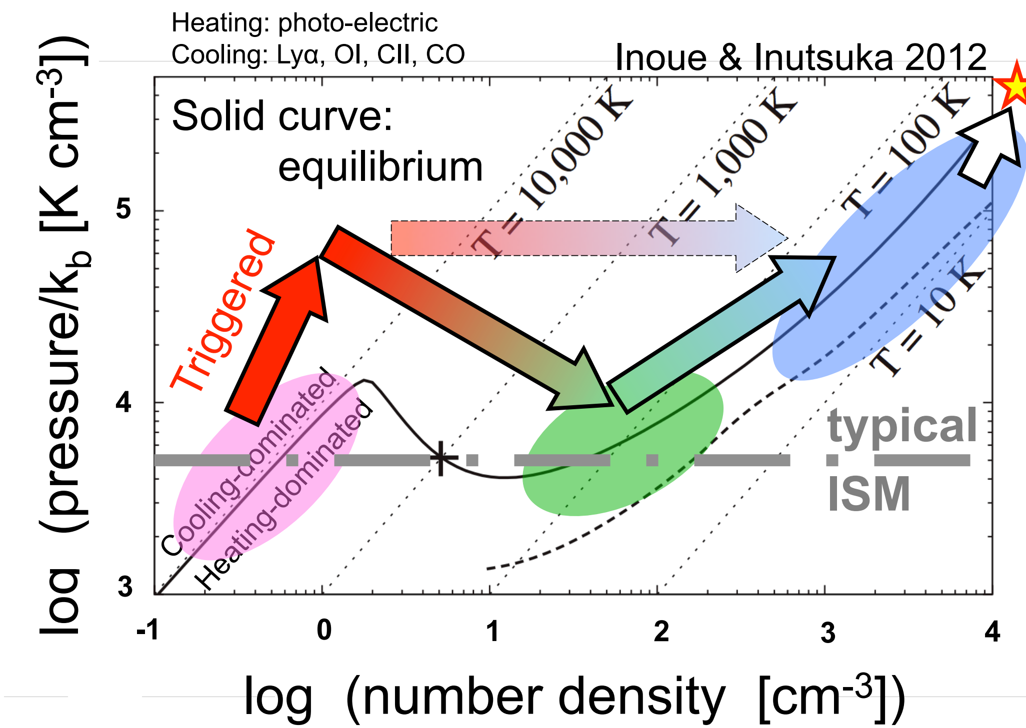
Model **ISM evolution on sub-grid scales** for galactic/ cosmological simulations.

Multiphase ISM @ present-day

Thermal equilibrium/instability



1) Warm Neutral Medium (WNM)

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

Most volume in the MW disk

2) Cold Neutral Medium (CNM)

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

3) Molecular Gas (MC)

H_2 (mostly bright in ^{12}CO)

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

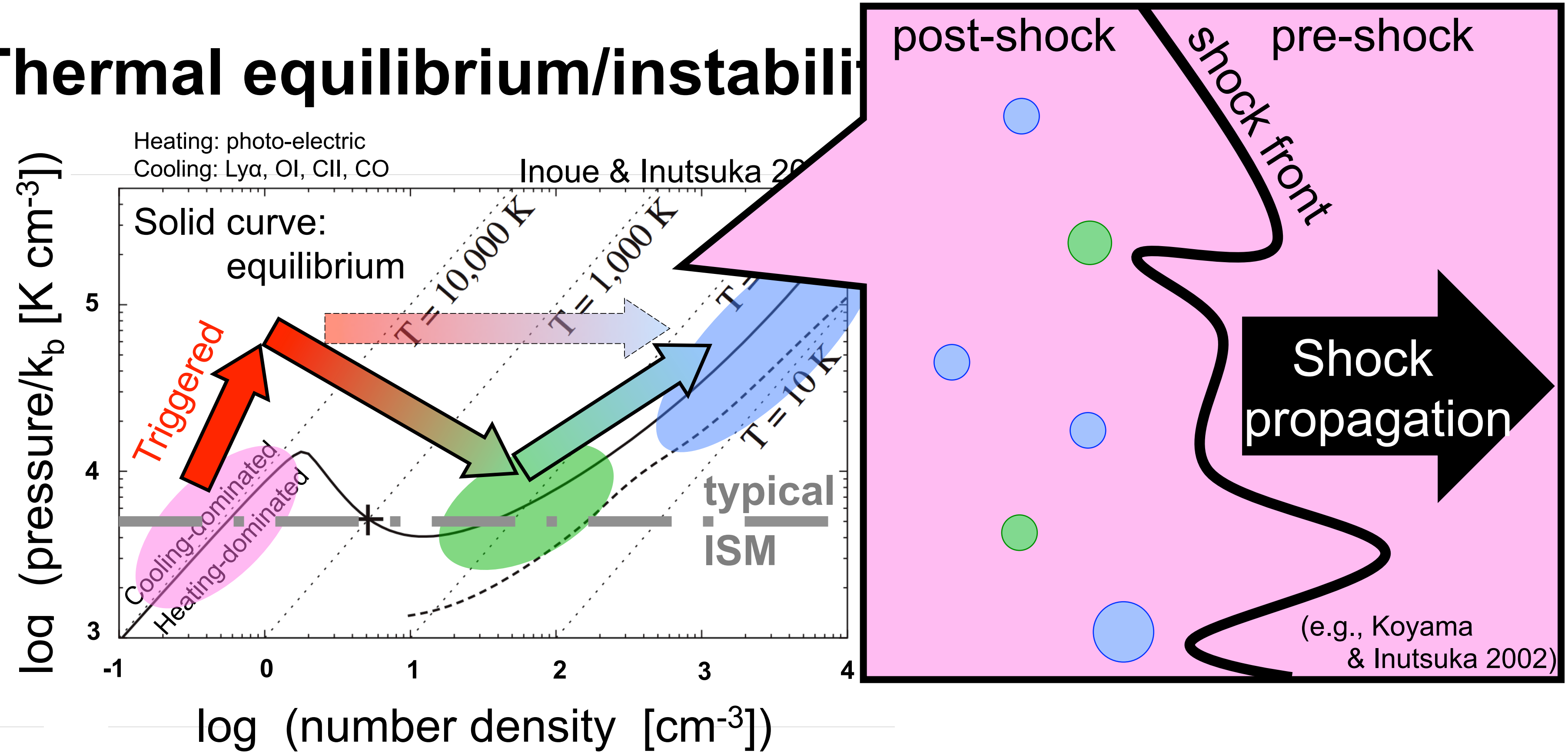
Thermally unstable; WNM self-gravity alone may not result in CNM/MC formation ...

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

Thermal equilibrium/instabili



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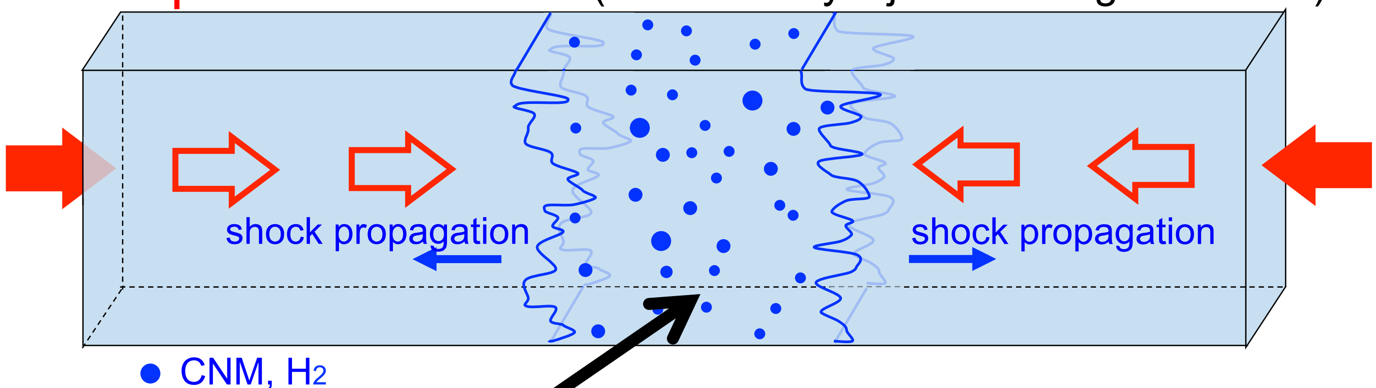
  Typical scale: sound speed x cooling time = **0.1-1 pc @ CNM-WNM**
- Shocks outgo beyond a simulation box...
  Let us calculate converging HI flows instead (, which has two shock fronts).

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

[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

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

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

➔ Effective γ gamma from ρ_2 (mean density in the post-shock region / WNM fraction) and M_1(shock propagation speed)

code: Inoue & Inutsuka 2008 hydro part

Finite Volume method with Eulerian remapping (Van Leer 1979)

Heating/Cooling: photo-electric, Lyα, 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) = box-center + dx(y,z)

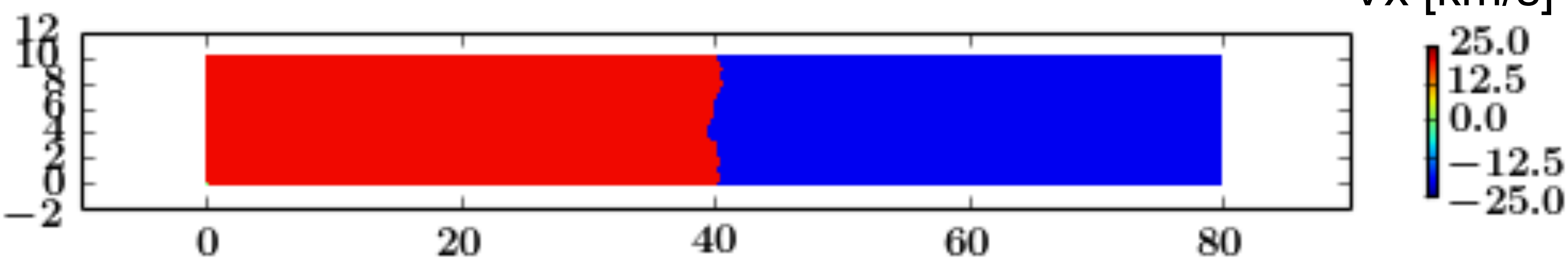
$$\delta x = \sum_{k_y}^{k_{y,\max}=10} \sum_{k_z}^{k_{z,\max}=10} P(k_y, k_z) \sin(k_y y + k_z z + \alpha_{k_y,k_z})$$

$$P(k_y, k_z) = A(k_y, k_z)\,|k|^{-11/6}\,.$$

(Amplitude is set so that its mean becomes 1pc.)

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

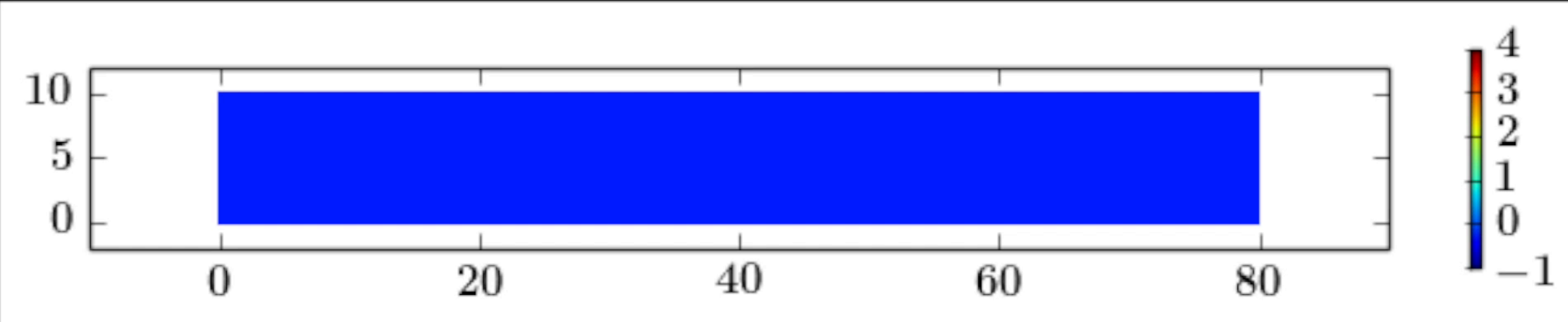
color: Vx [km/s]



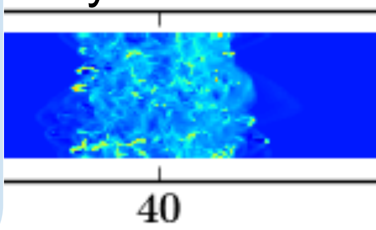
Time-Evolution

Density slice

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



Summary



✓Background: model the multiphase ISM

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

✓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 ~ 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 (Vinflow,t)