The histogram of bubble sizes in spiral galaxies

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Introduction: Bubble Filament Paradigm Inutsuka+2015 Pineda+2023

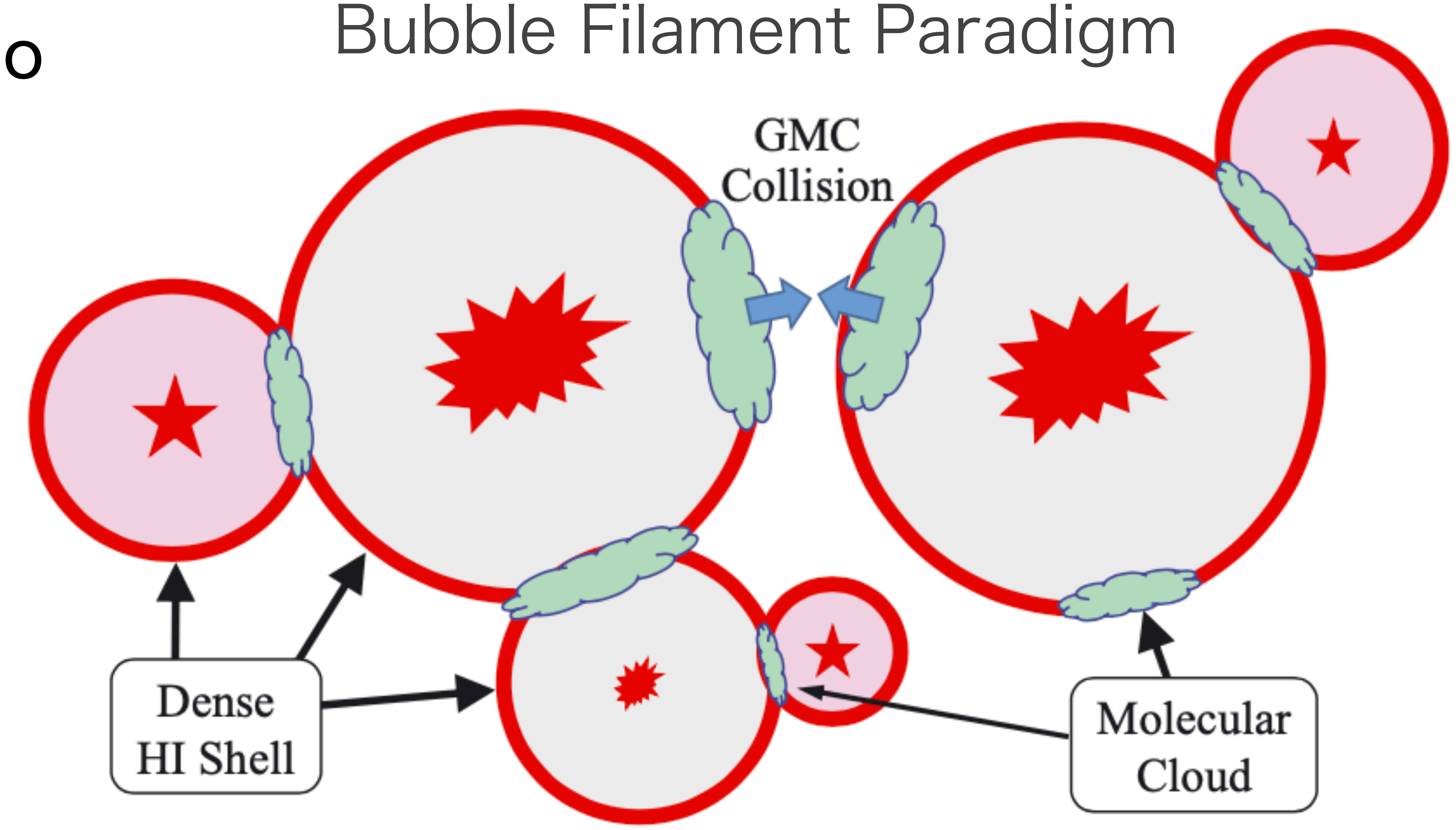
Bubble Filament Paradigm scenario

① **Multiple shell-shaped shocks expanding**

② **Their shock compress ISM multiple time**

③ **ISM is going to be molecular cloud**

Bubble Filament Paradigm



Inutsuka et al.2015

▶ **They predicted the presence of bubbly structure in the Milky Way Galaxy.**

Observation of bubbly structure galaxies Watkins+2023

Observation of NGC628 by JWST

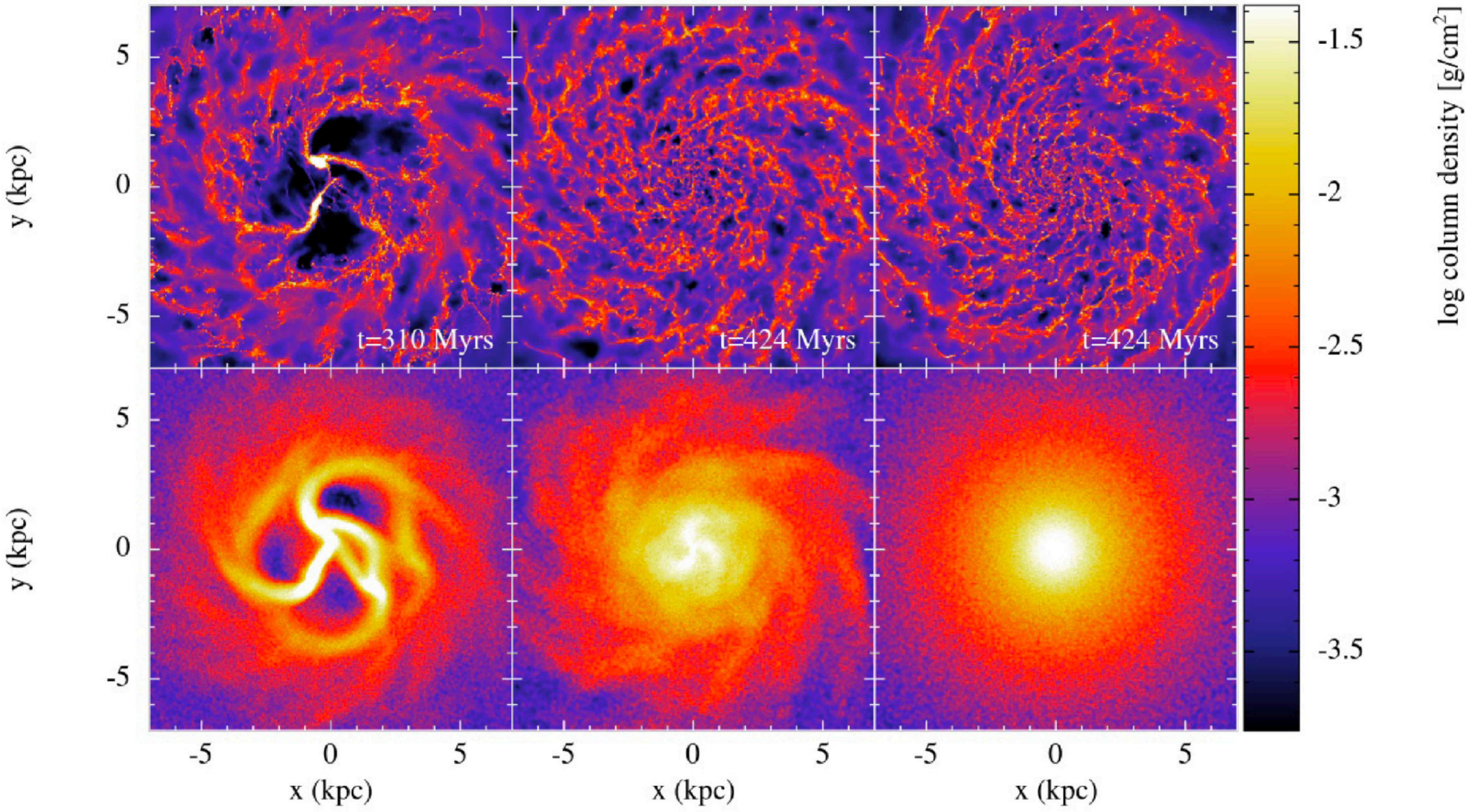
Are they Super Nova Remnants? Or HII regions?

M74/NGC628(Judy Schmidt)

Recent simulation result Dobbs+2018

Bubbly structures were provided with SNR feedback

Galaxy dynamics simulation



Dobbs+2018

Bubble structure resulting in simulation

is affected by modeling and resolution

Analytical bubble distribution model

should be helpful

Our goal : prediction of the bubble size distribution

Outline of this work

- Simulate the expansion of a SNR as a function of time
- Change the ambient density to determine dependency of SNR radius on density
- Create histogram of bubble size distribution in a galaxy disk
- Compare resulting histogram with observation

Simulation setting

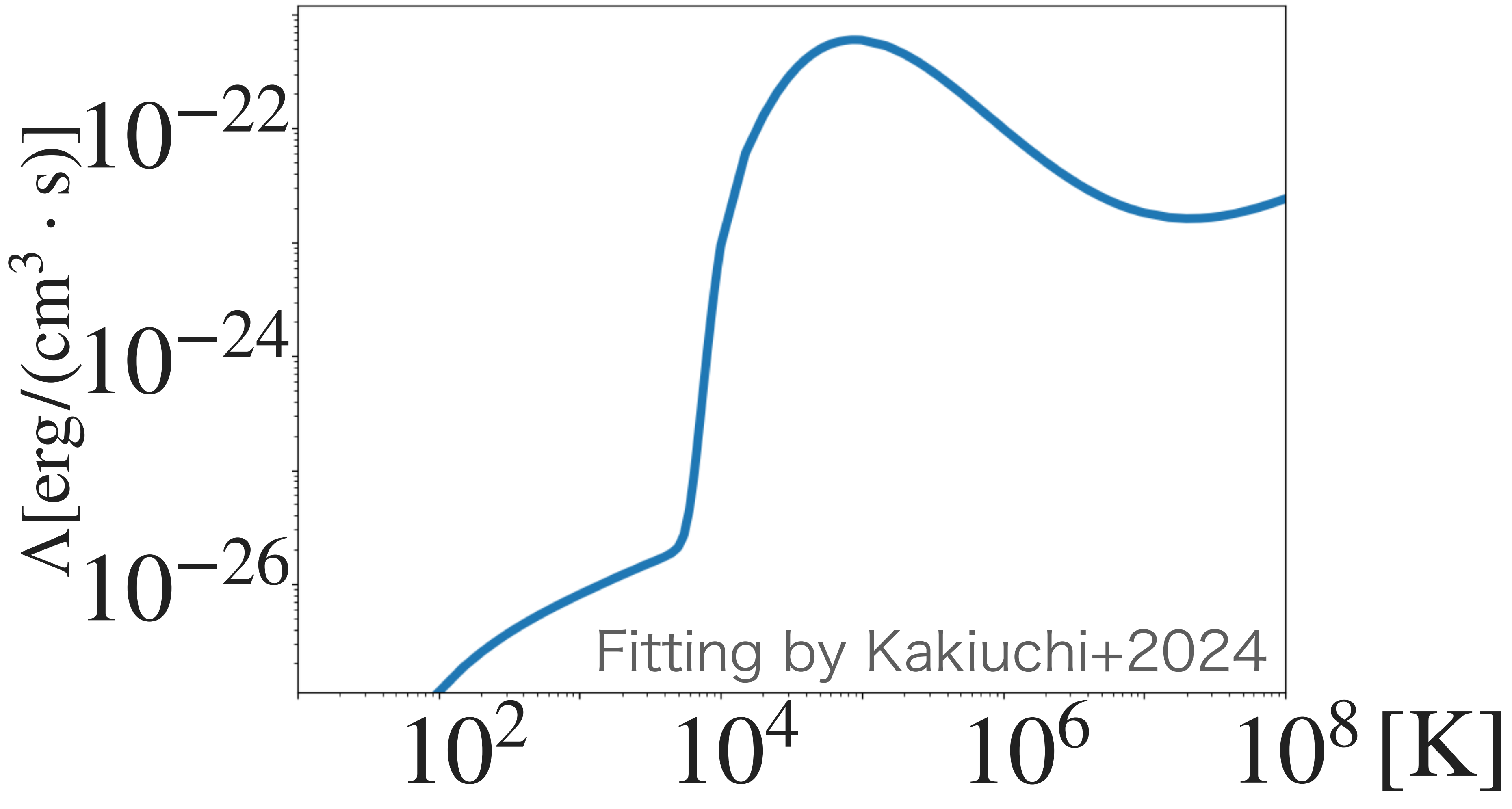
Equation (Spherically symmetric Lagrangian code)

- Continuity $$\frac{dV}{dt} = -\frac{1}{\rho r^2}\frac{\partial r^2 v}{\partial r}$$
- Motion $$\frac{dv}{dt} = -\frac{1}{\rho}\frac{\partial p}{\partial r}$$
- Energy
$$\frac{de}{dt} = -\frac{1}{\rho r^2}\frac{\partial}{\partial r}r^2\left(pv - \kappa(T)\frac{\partial T}{\partial r}\right) + \Gamma - n\Lambda(T)$$
Thermal conduction — Cooling +heating
- Equation of state $p = K\rho^\gamma$

Cooling function

Sutherland&Dopita 1993

Ly-α CII	$T < 10^4$K
C O SI Fe	$10^4\text{K} < T < 10^7$K
Bremsstrahlung	$T > 10^7$K



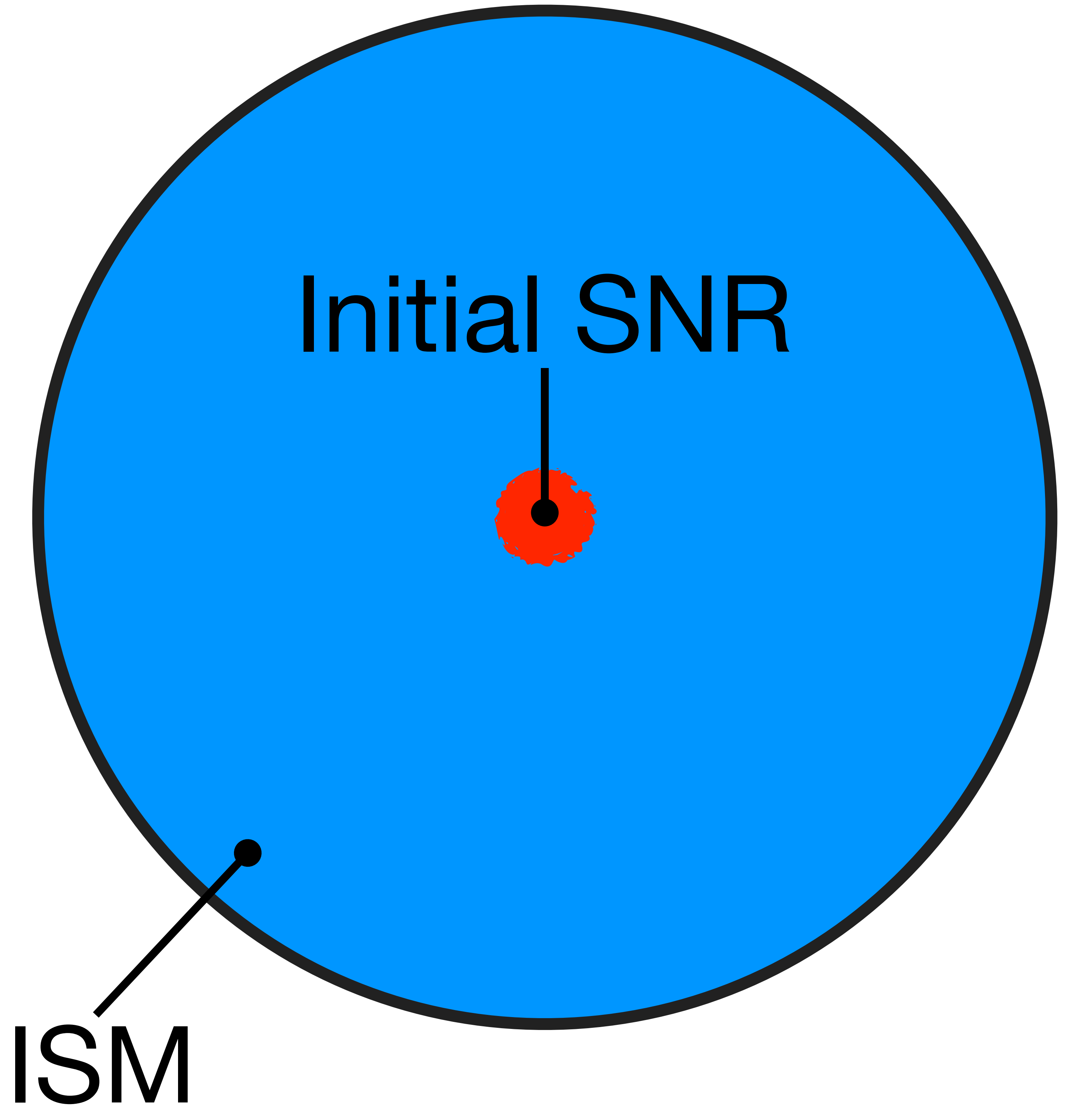
Thermal conduction

$\kappa = 2.5 \times 10^3 T^{1/2}$ erg/(s · K · cm) $T < 4.0 \times 10^4$K (Parker 1953)

$\kappa = 6.0 \times 10^{-7} T^{5/2}$ erg/(s · K · cm) $T > 4.0 \times 10^4$K (Spitzer 1962)

Simulation setting

Spherical symmetry



- Uniform ambient medium
- Thermal equilibrium

Initial condition

SNR = thermal bomb

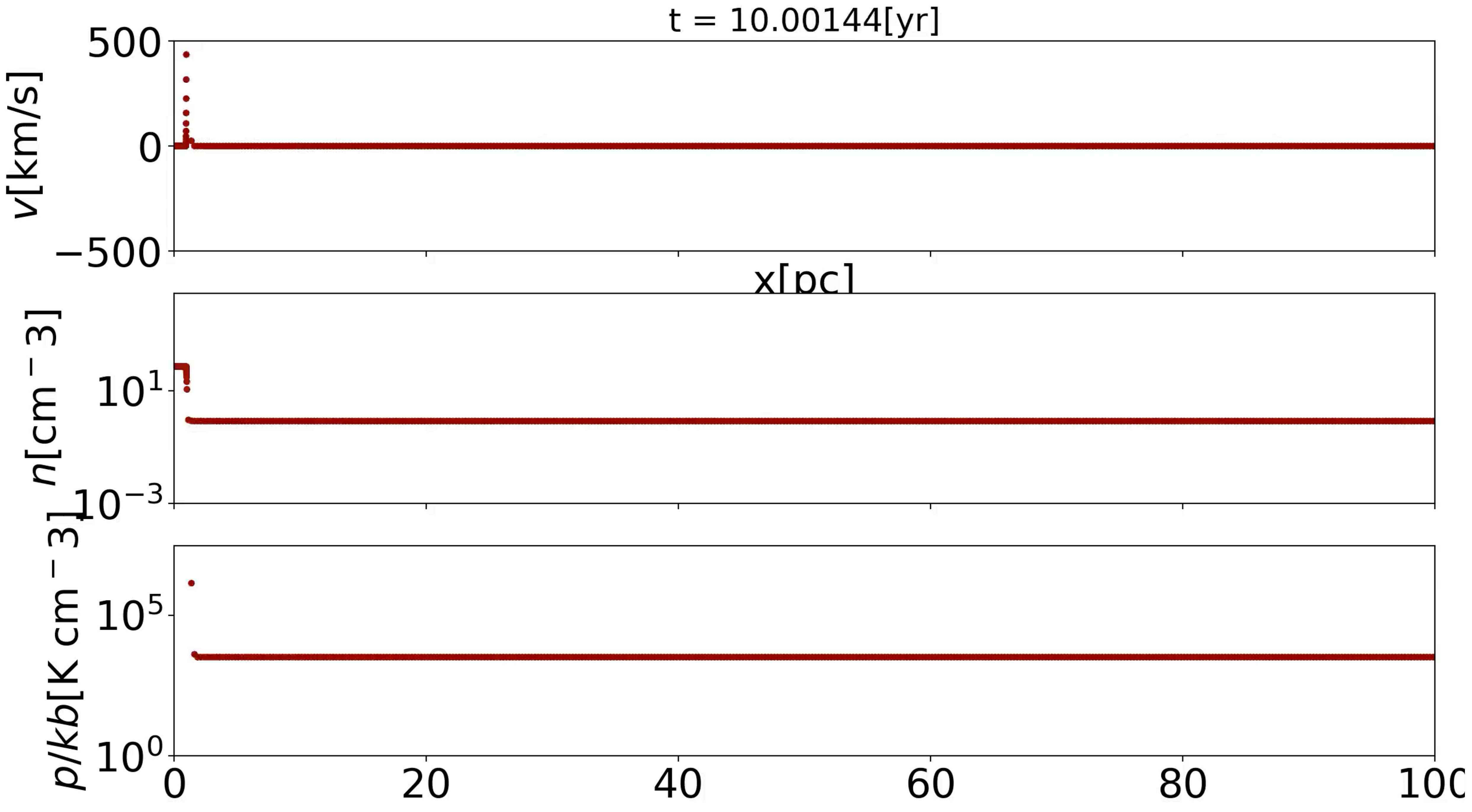
Energy	Mass	Size
10^{51}erg	$8M_{\odot}$	1pc

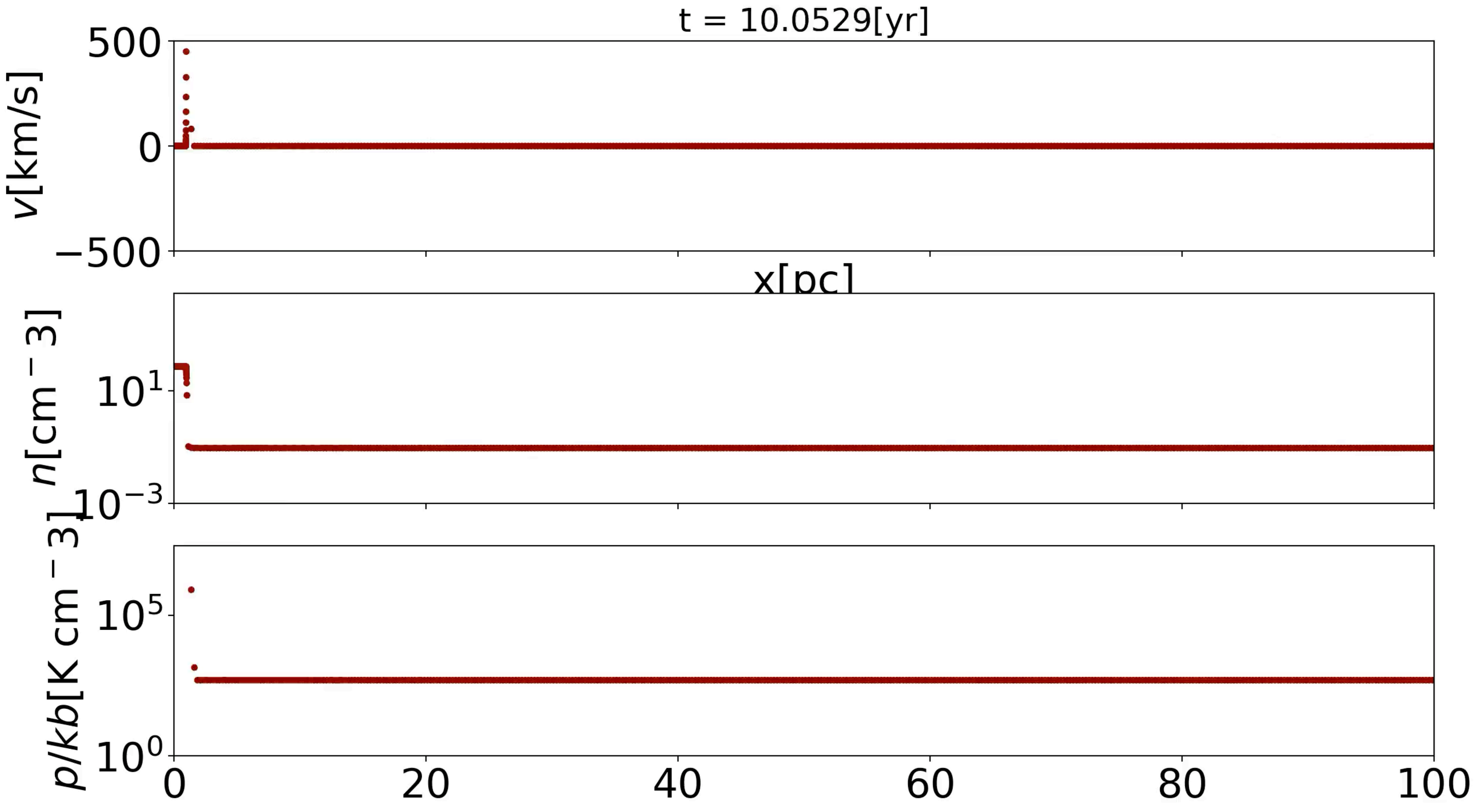
ISM parameters

Number Density [/cc]	Temperature[K]	Cell size[pc]
0.5	6900	0.25
1.0	5000	0.25
2.0	1600	0.25
5.0	390	0.25
10.0	180	0.25

Simulation result

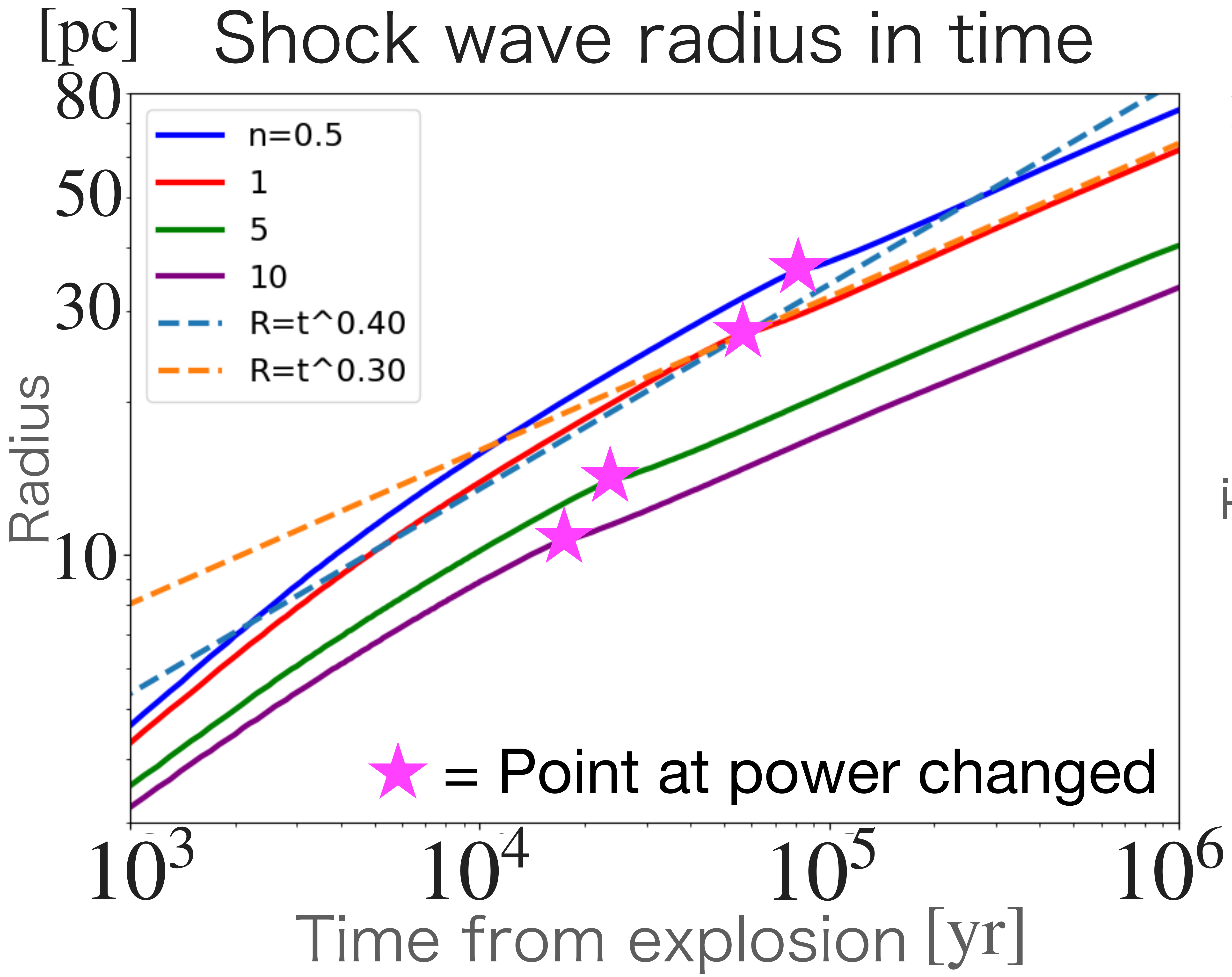
$n = 1.0/\mathrm{cc}$ $n = 0.5/\mathrm{cc}$

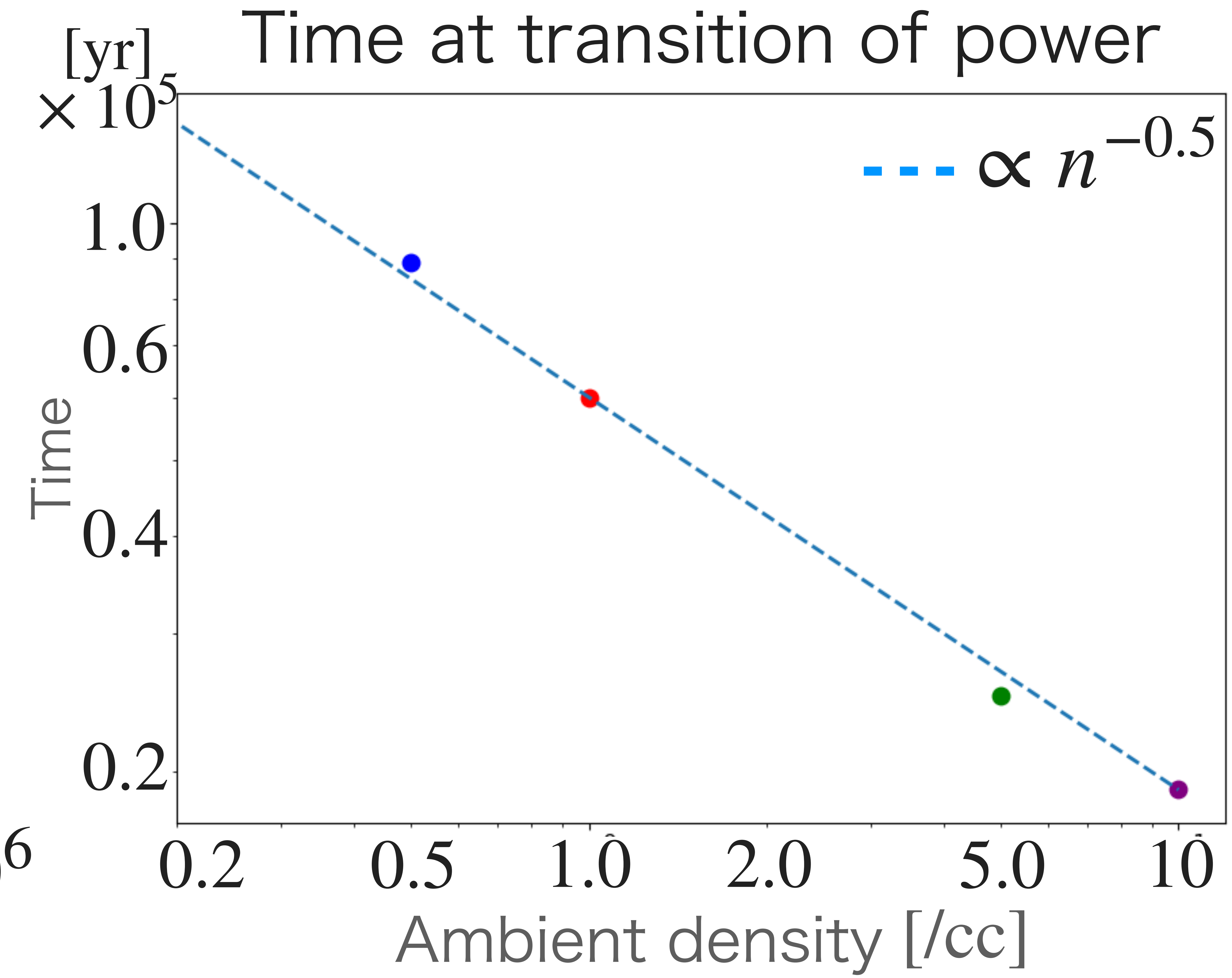




▶ The expansion speed and time where dense shell formed are different and depending on ambient density

SNR expansion under various ambient density

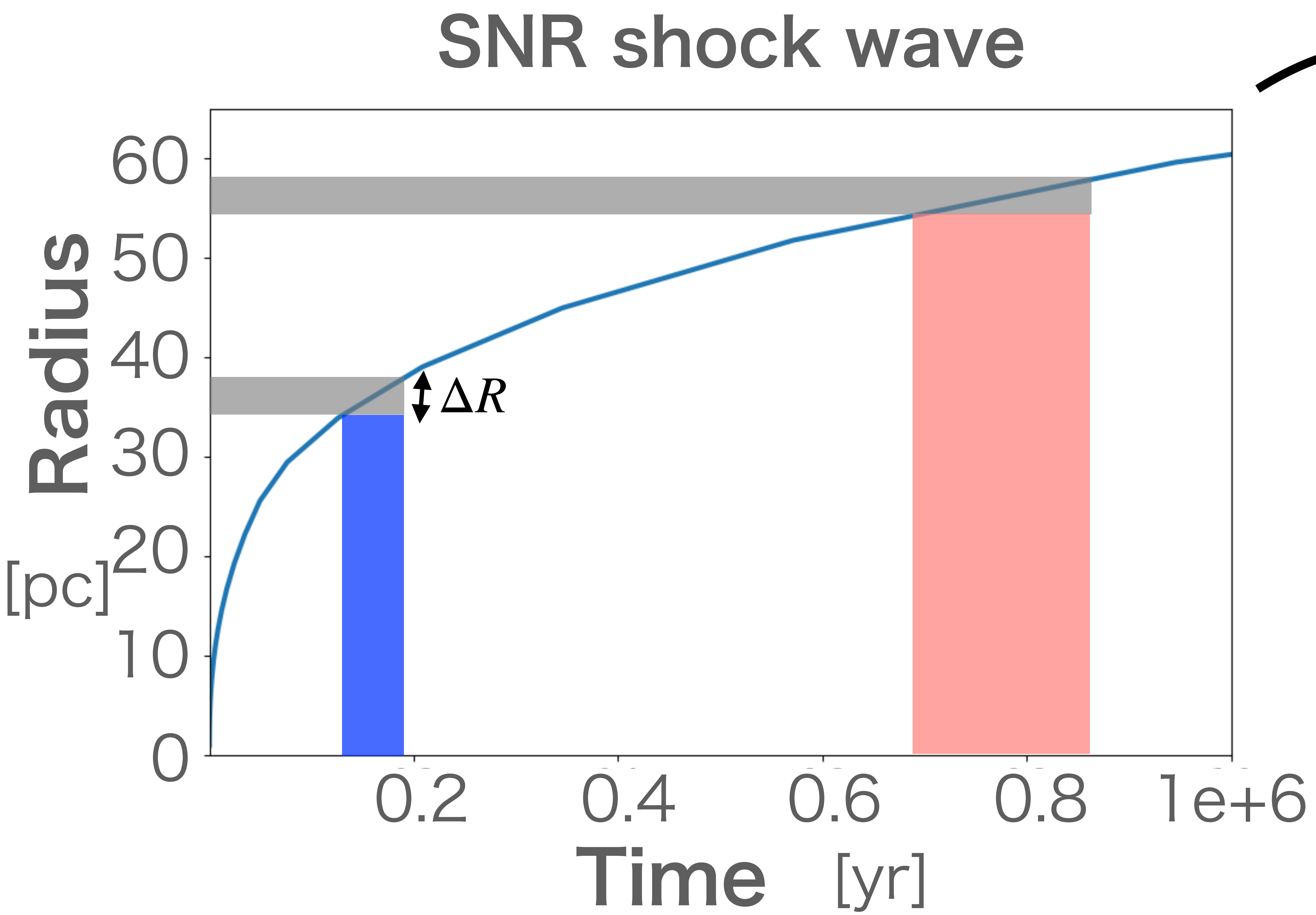


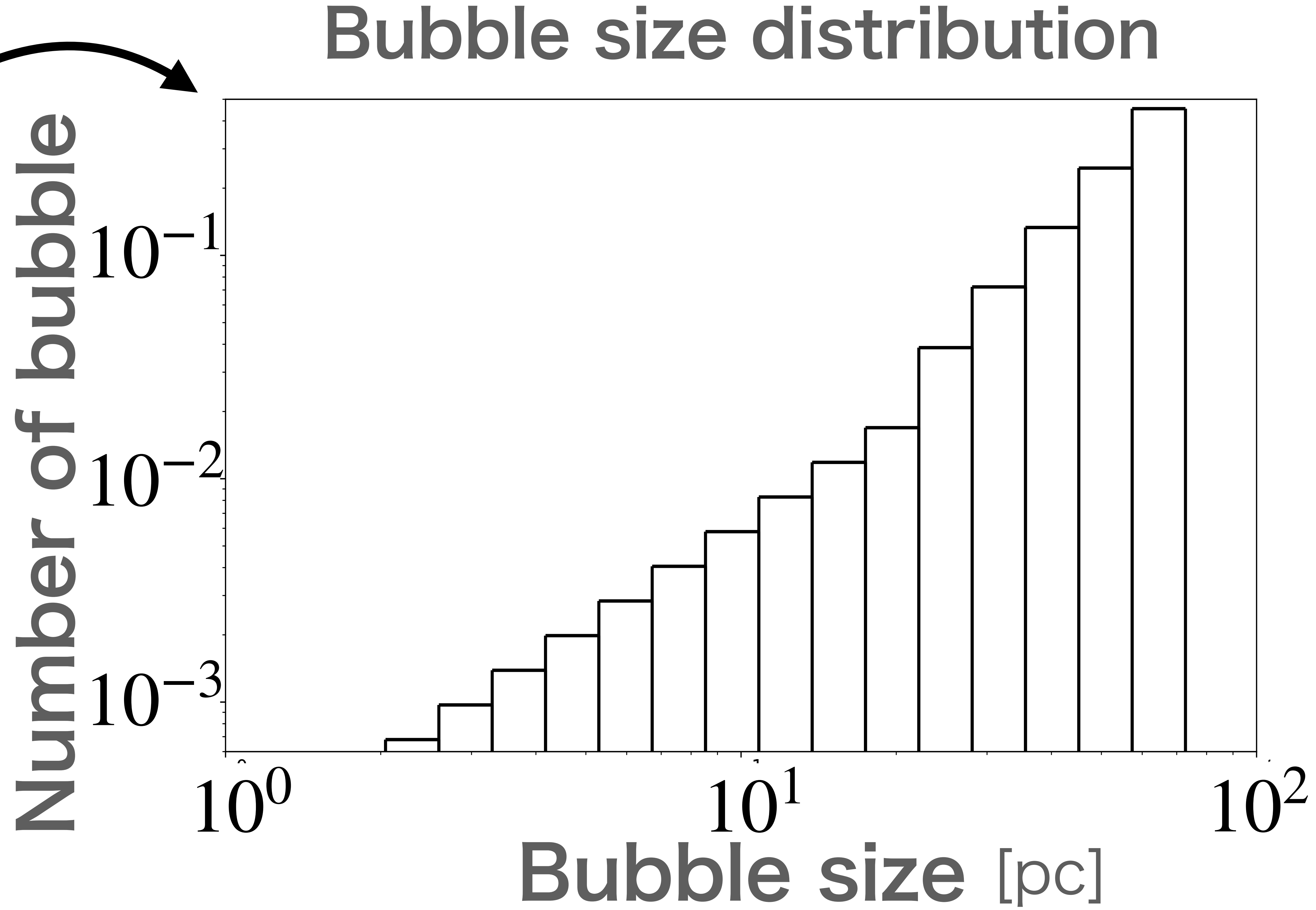


We are going to make model describing bubble size distribution with these relation

How to create bubble size distribution on galaxy

We assumed statistically steady bubble number on galaxy

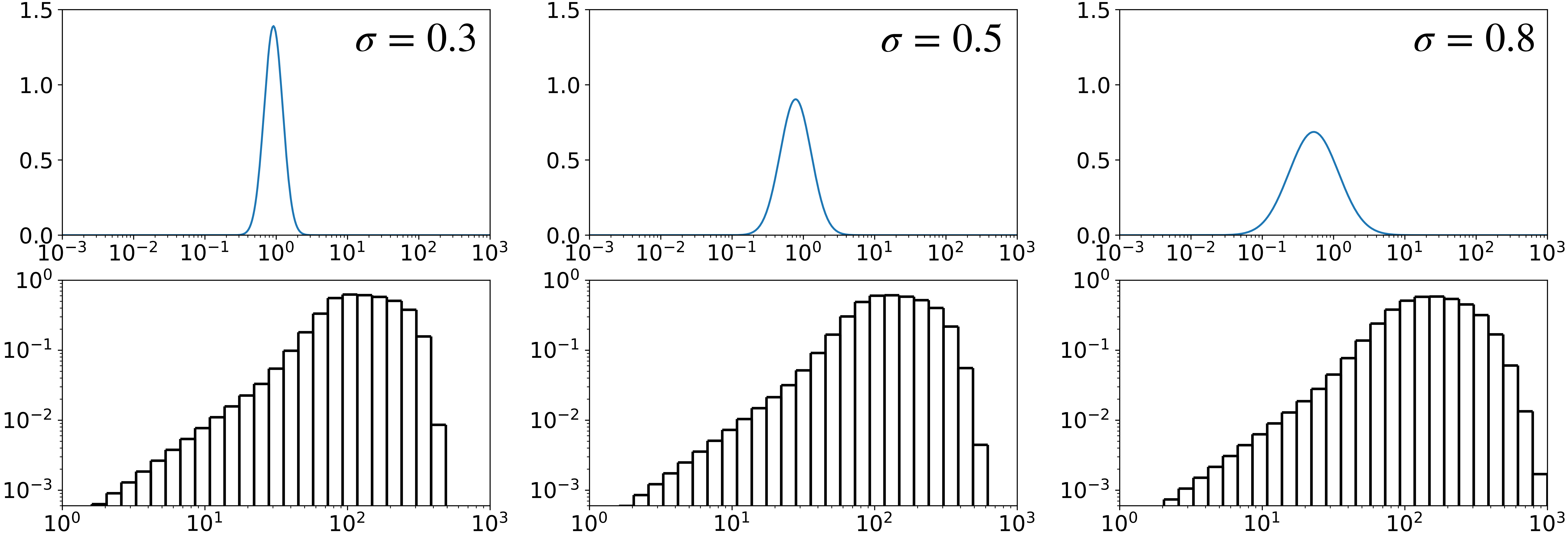




Dependency of bubble size distribution on density profile

Density profile : $f(n) = \frac{1}{\sqrt{2\pi}n\sigma} \exp\left(-\frac{(\ln n - 1.0)^2}{2\sigma^2}\right)$

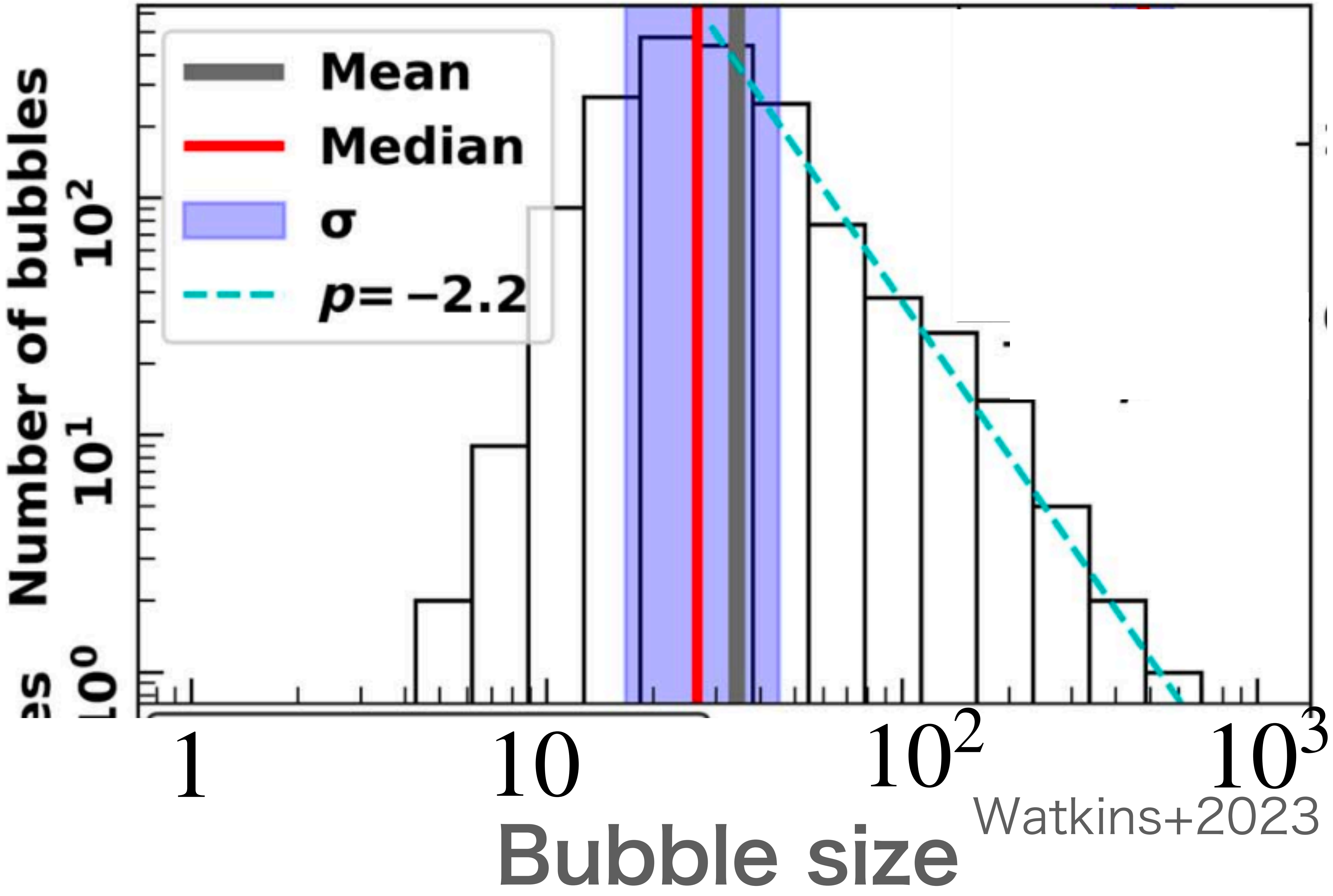
PDF



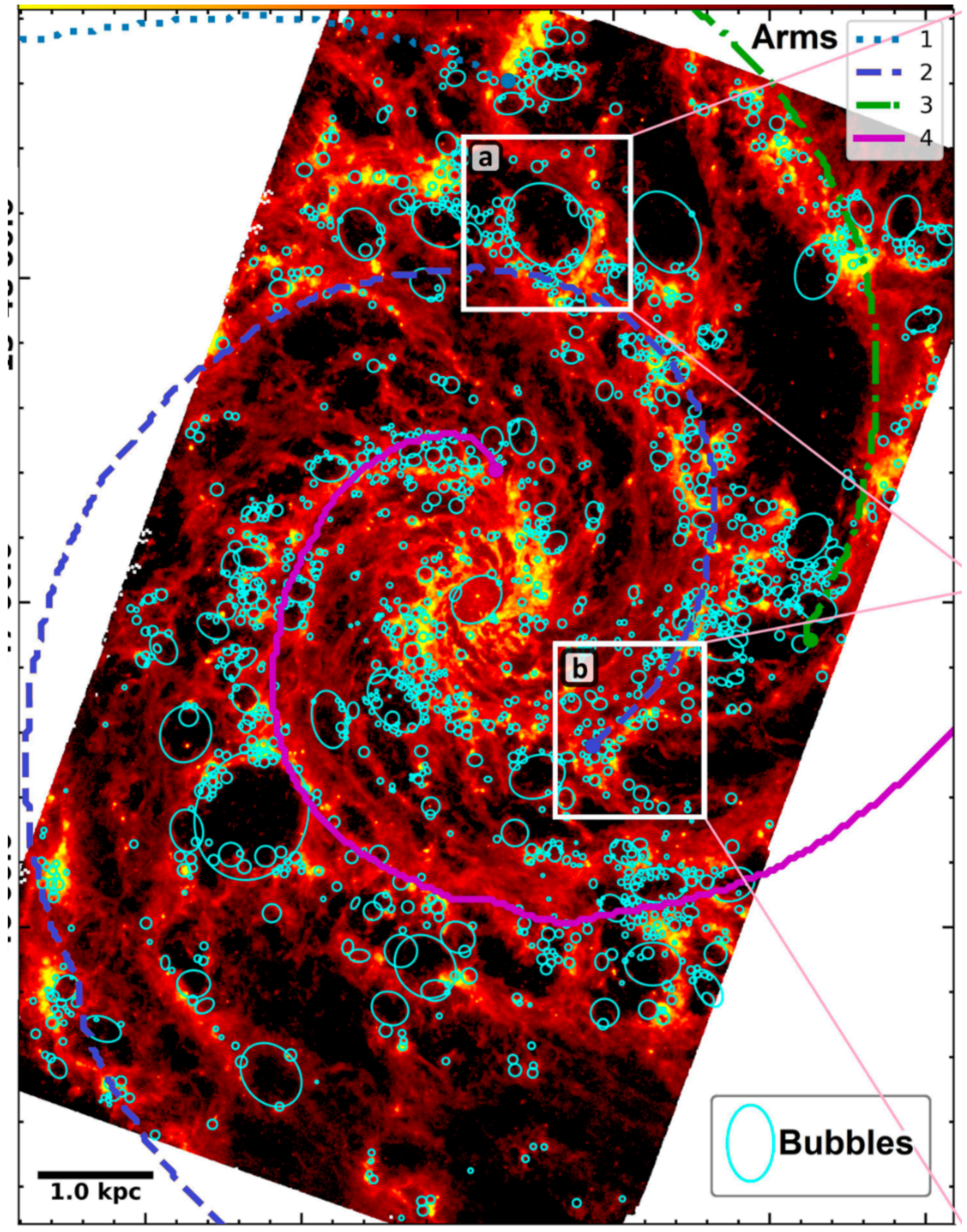
- The larger bubble side of the histogram is much affected by population of lower density ambient medium

Comparison with observation

Observation bubble histogram



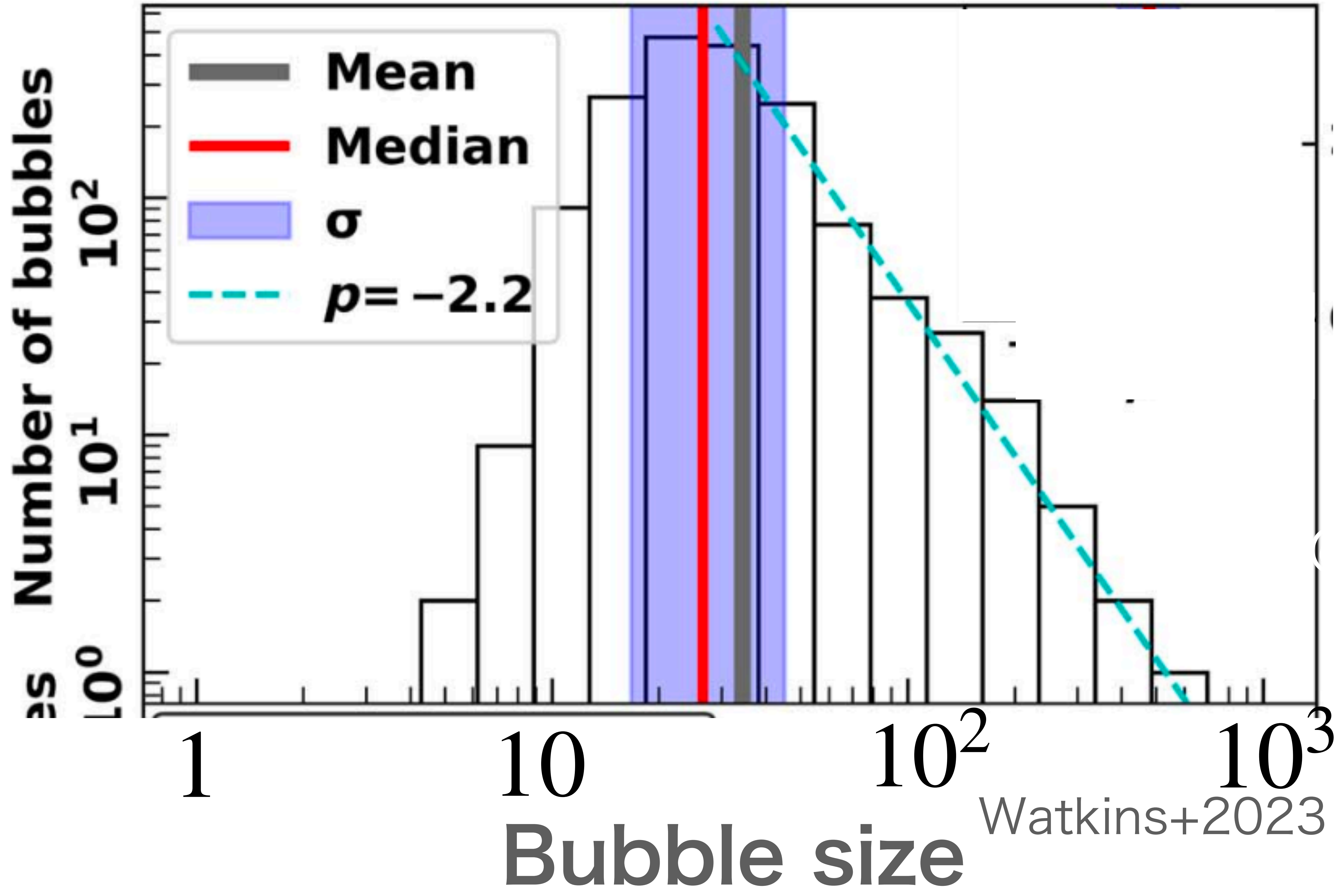
Watkins+2023



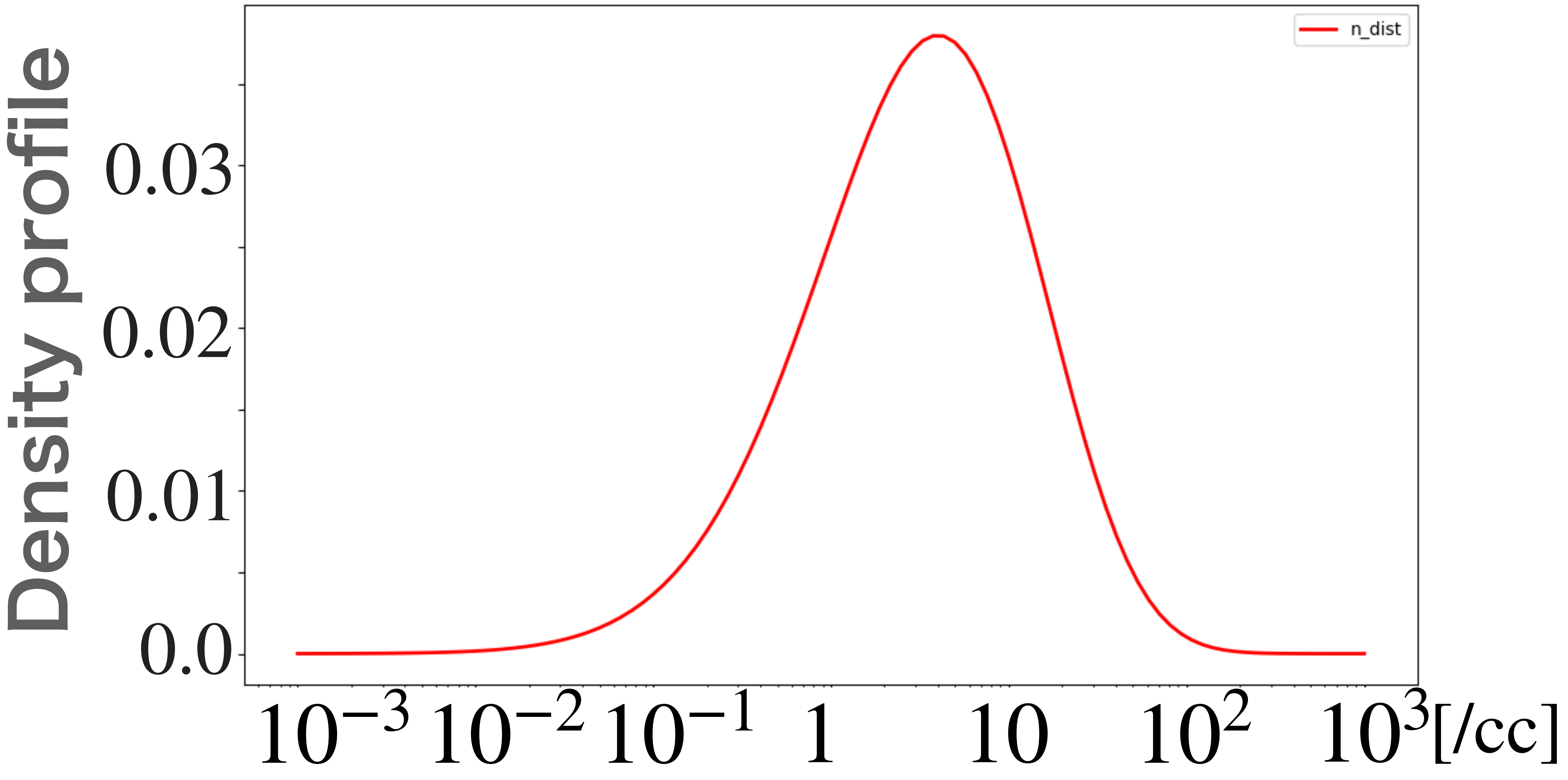
Watkins+2023

Comparison with observation

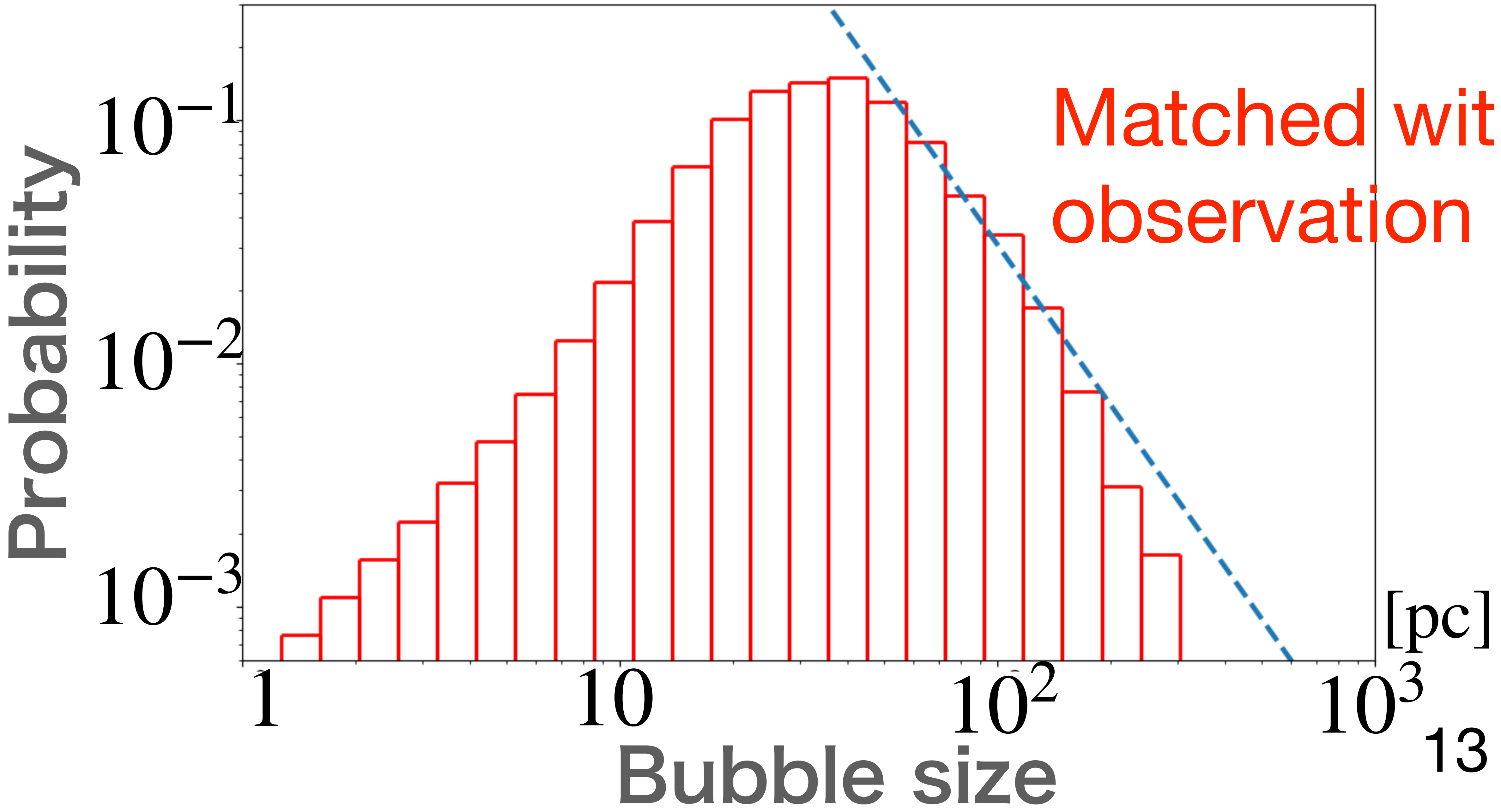
Observation bubble histogram



PDF of ambient density



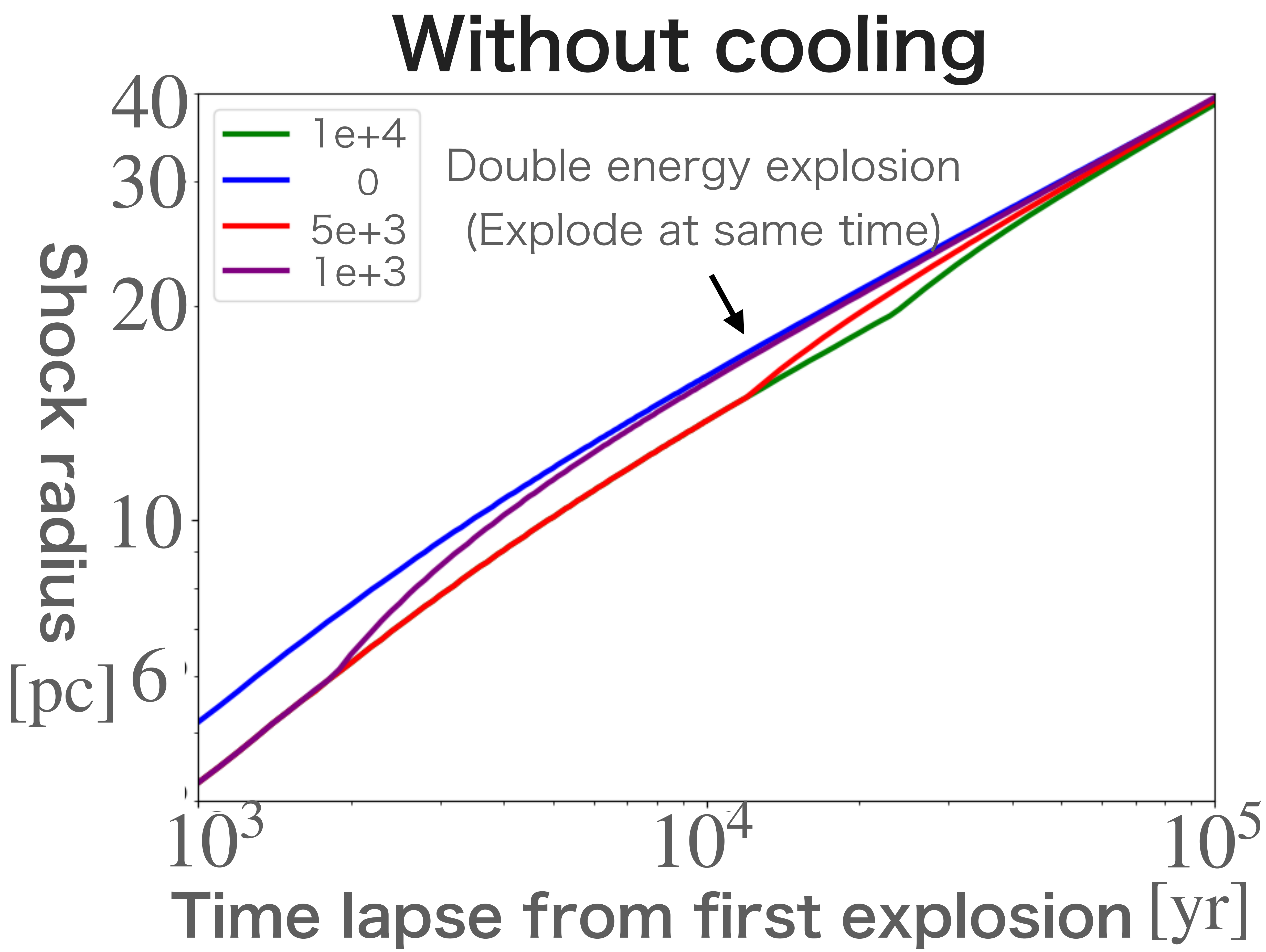
Our prediction of bubble histogram



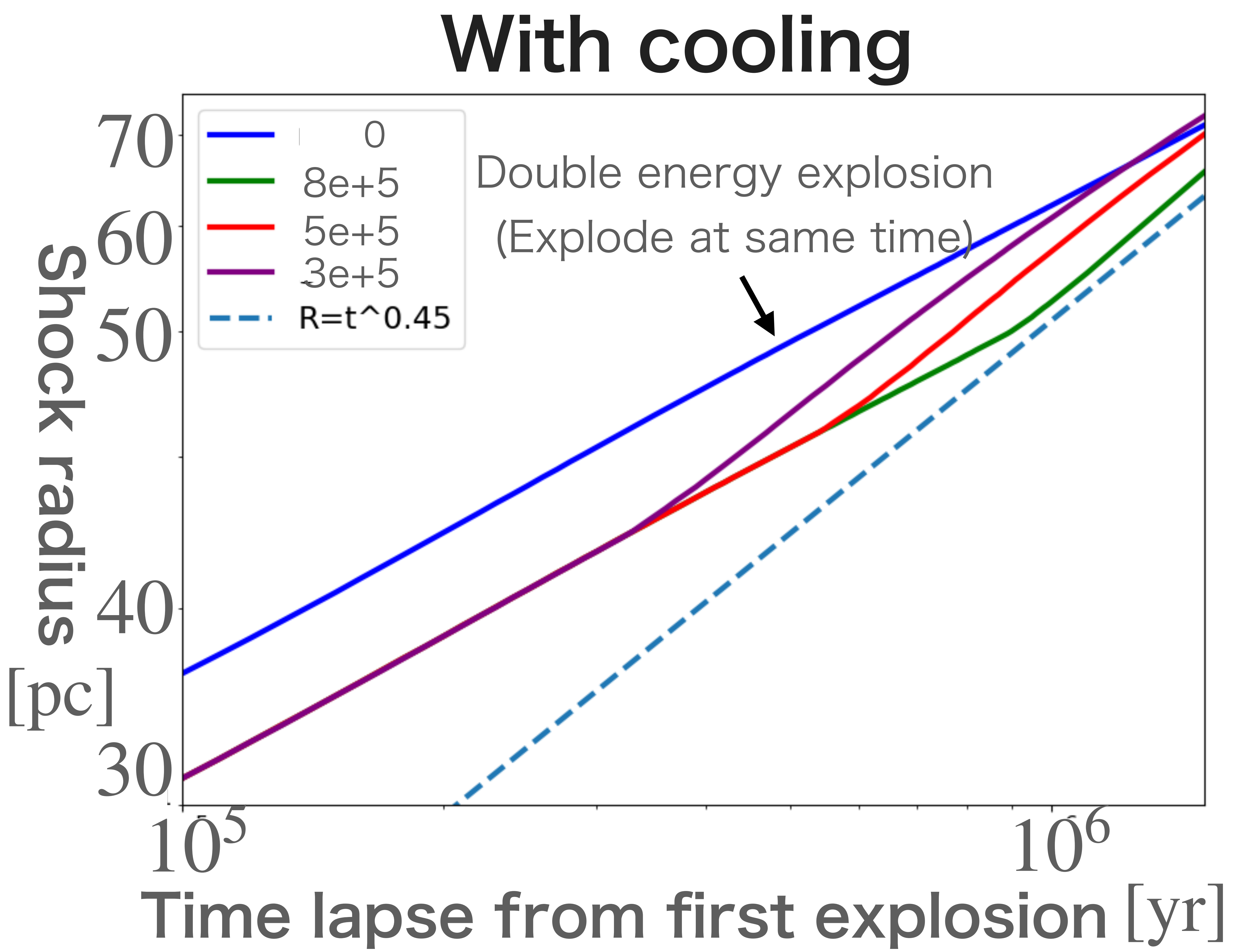
Summary

- Performed SNR expansion simulation
- Theoretically created bubble size distribution from numerical simulation
- Compared observed histogram and theoretical prediction
  (For SFR = a few Msun/yr)

Multi-explosion calculation



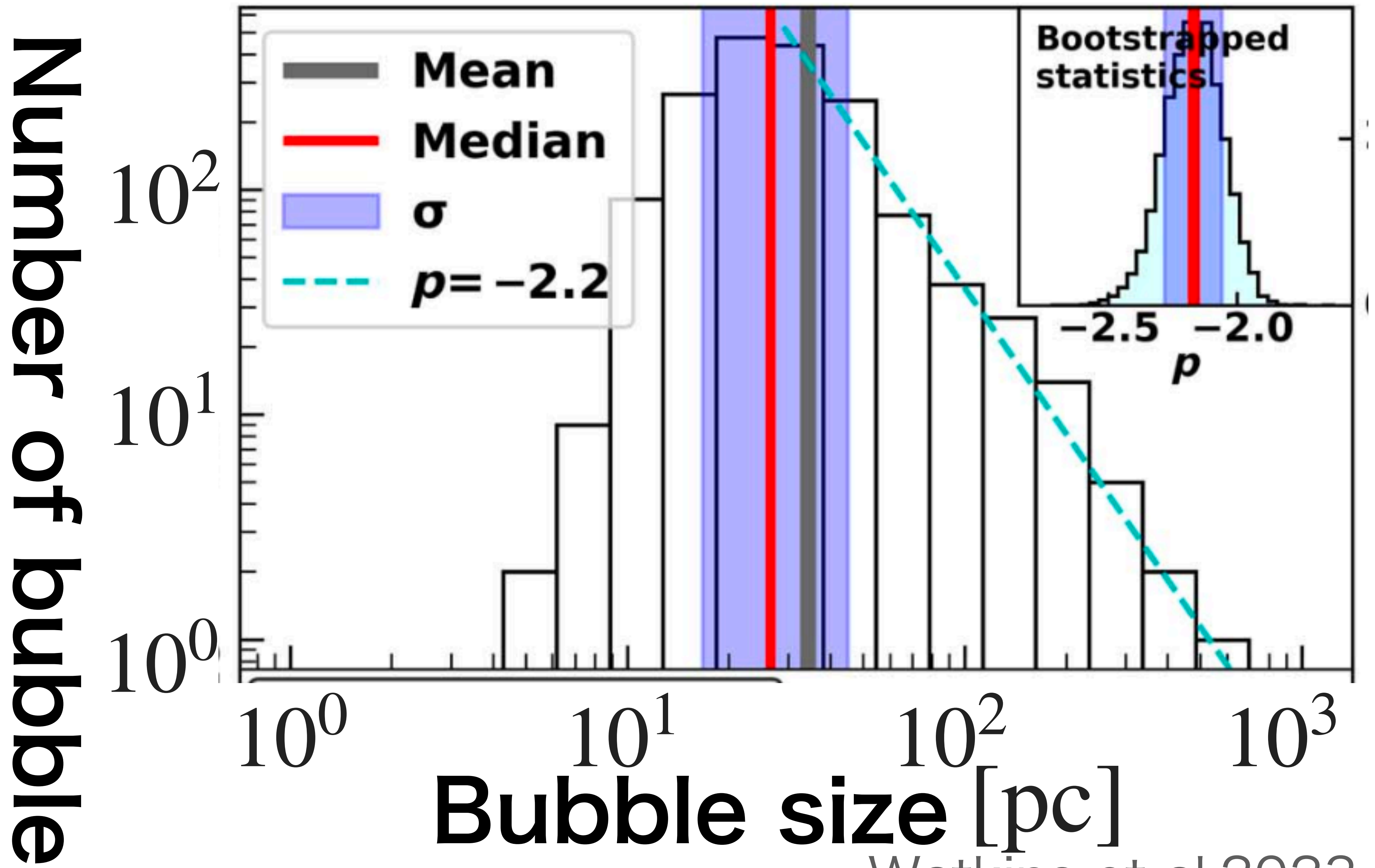
Converge to same-exp



Not converge

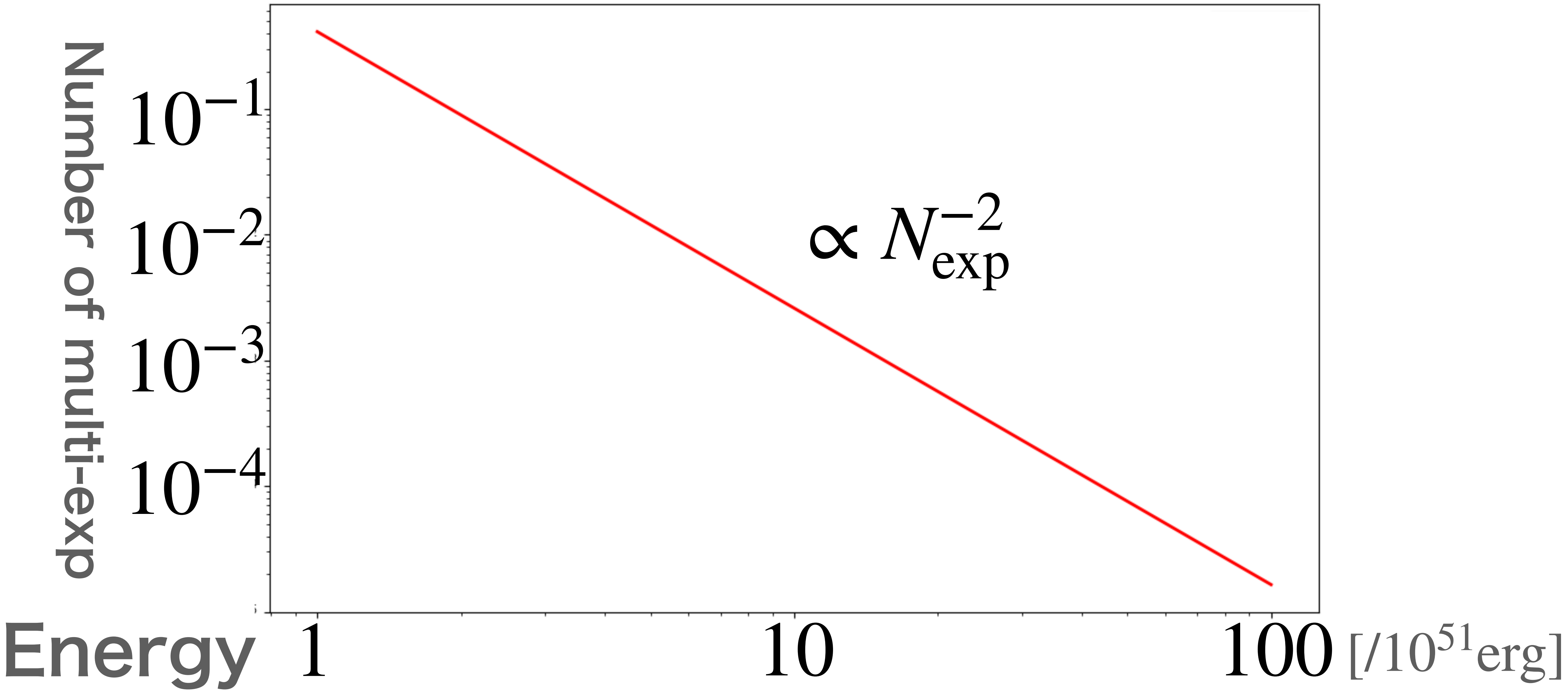
Histogram included multi-explosion

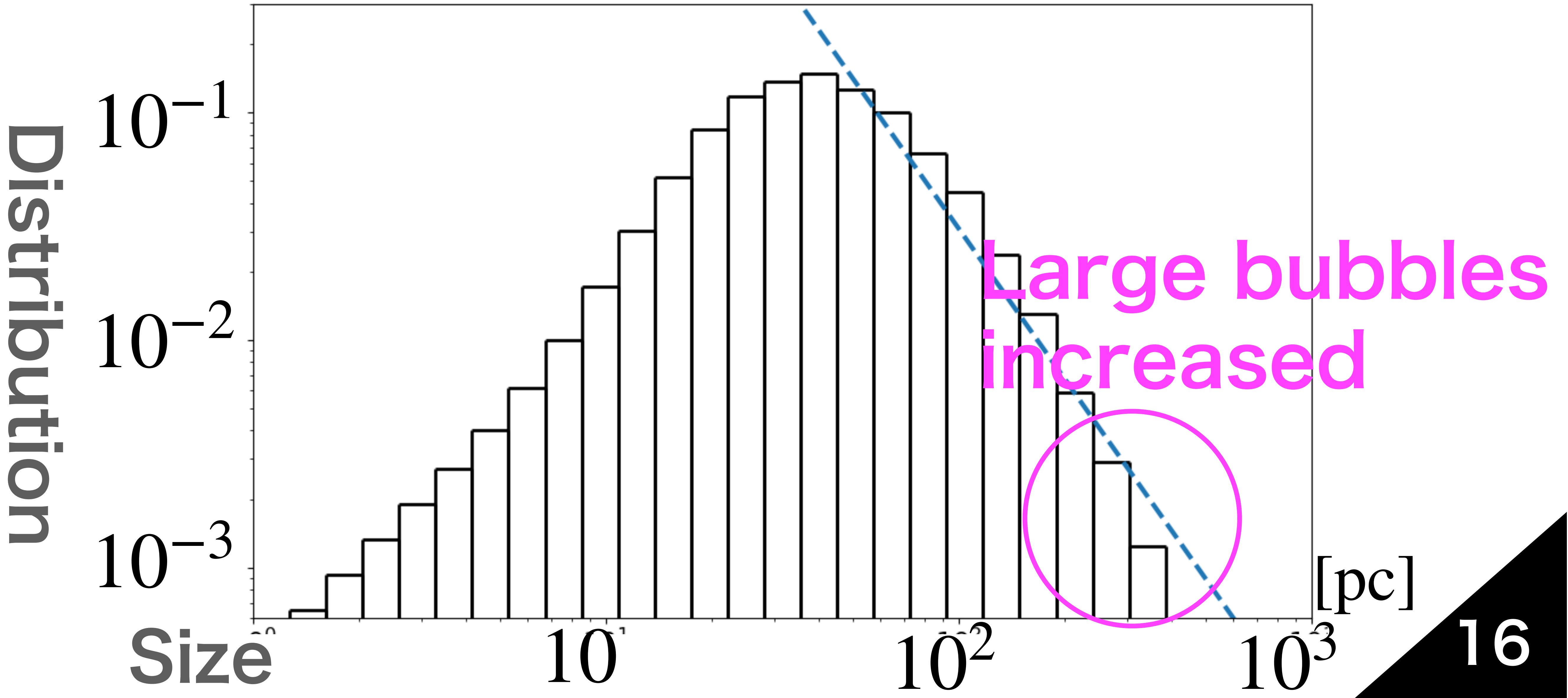
Histogram from observation



Watkins et al.2023

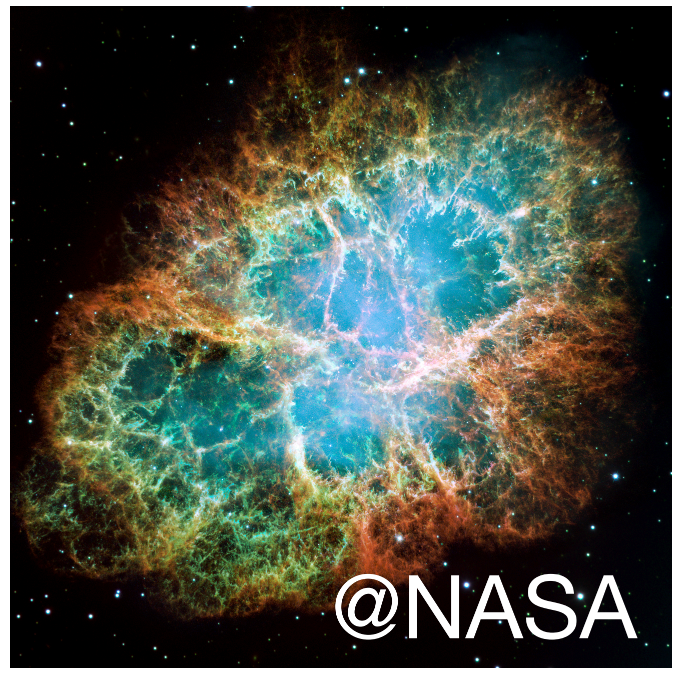
- Typically 30pc around
- Largest size is 1kpc
- Large bubble follow Power law



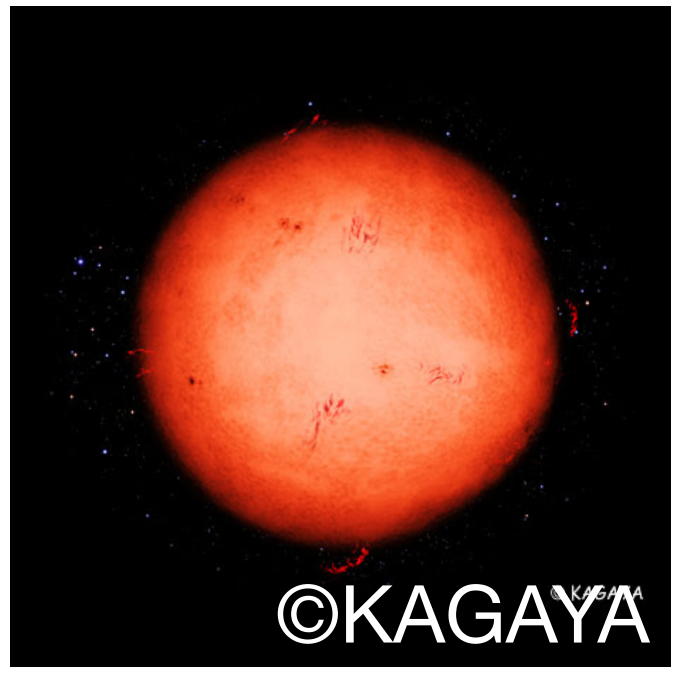


Introduction

SNe



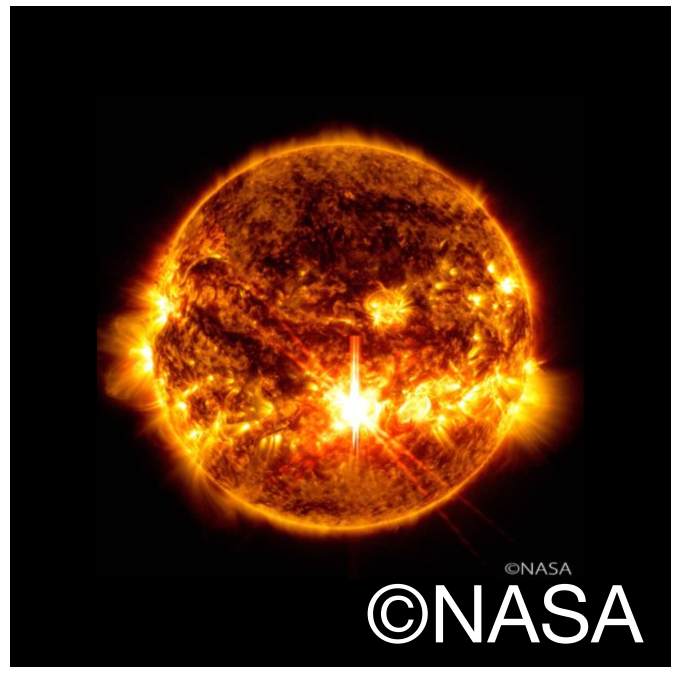
RSG



ISM

Circulation process on galaxy

Star

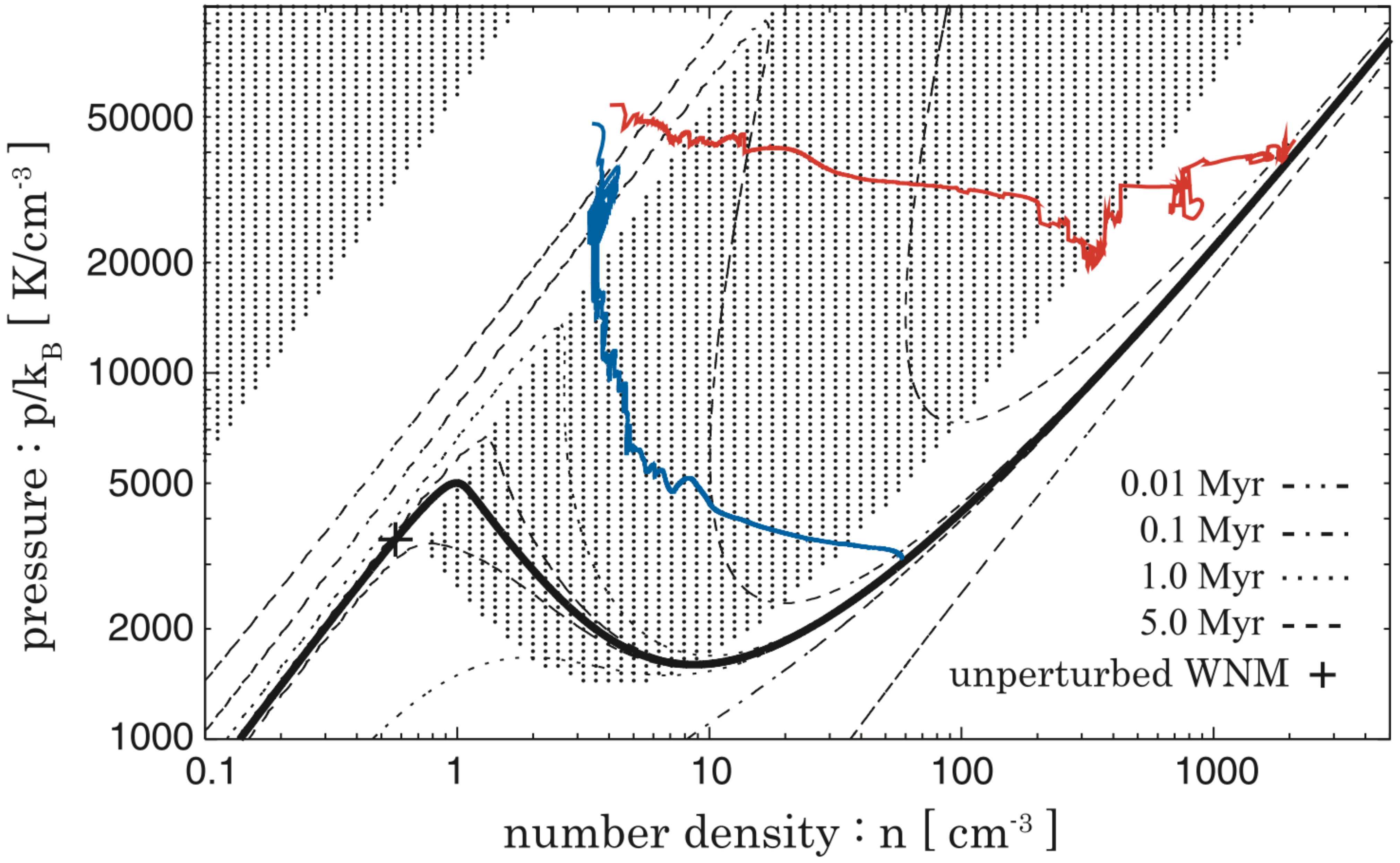


Molcular cloud

Protostar

Cooling collapse of magnetized ISM

Inoue&Inutsuka 2008



Single shock can not make ISM enough dense

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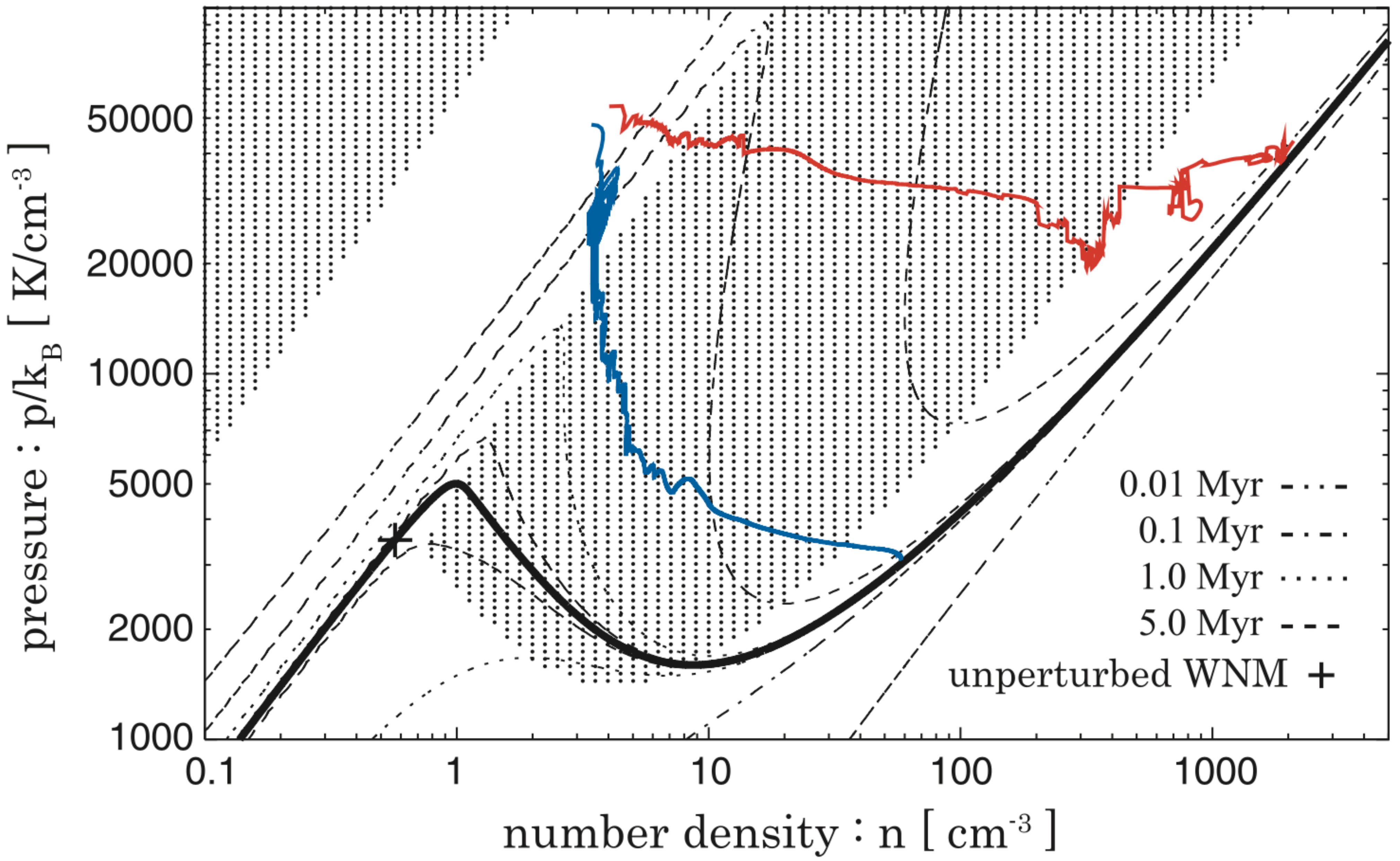
Inoue&Inutsuka 2008



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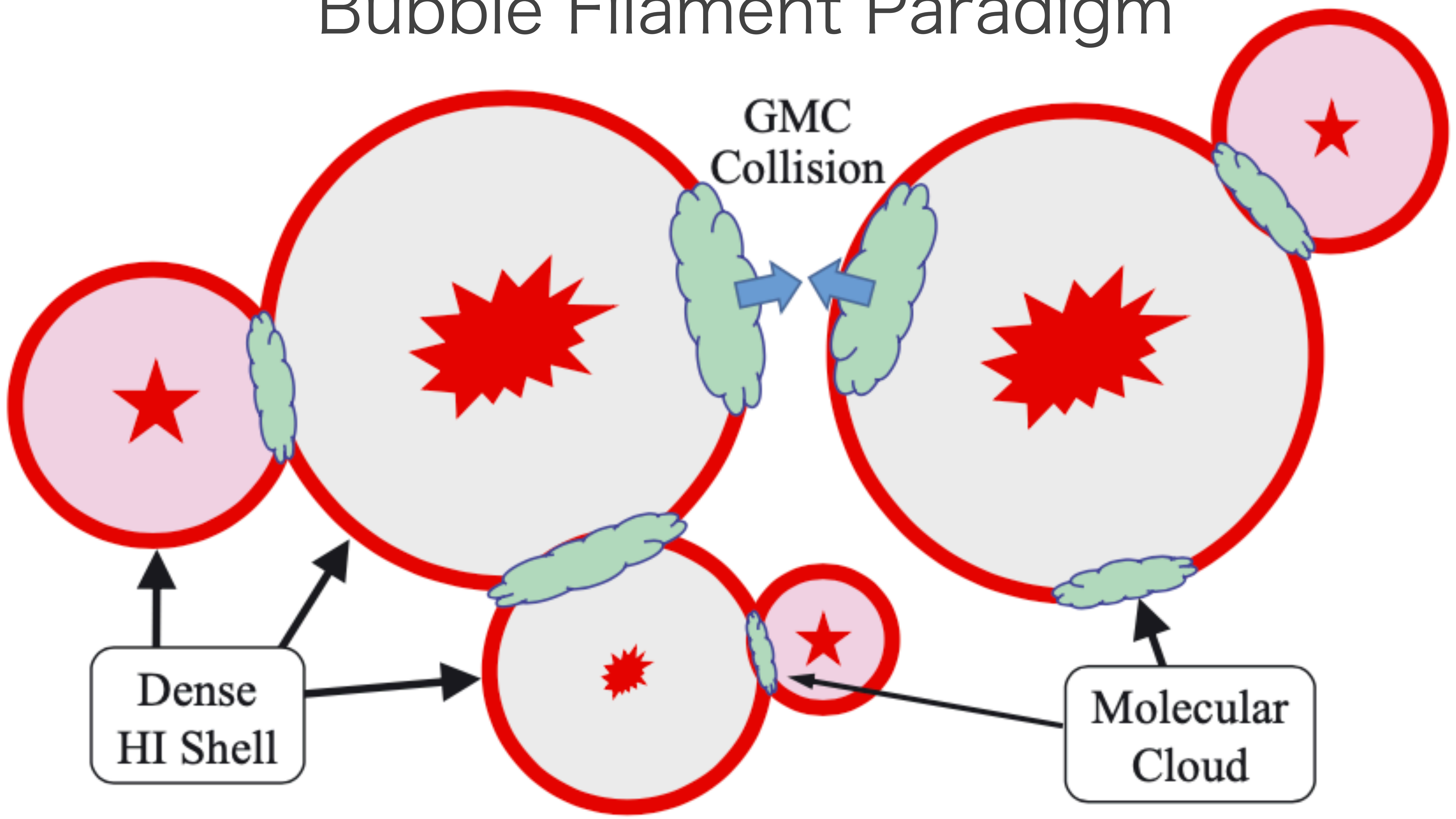
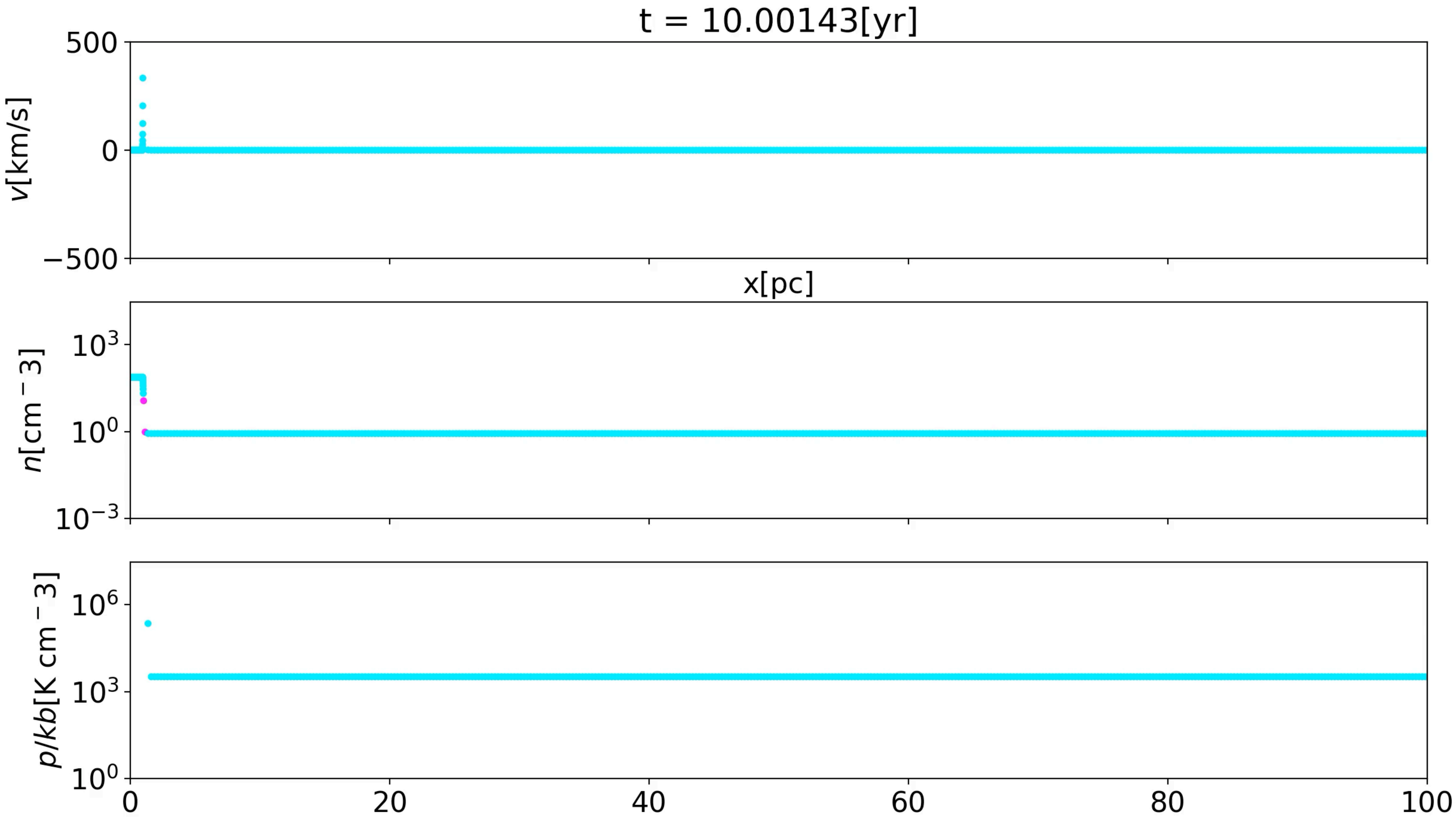
Bubble Filament Paradigm



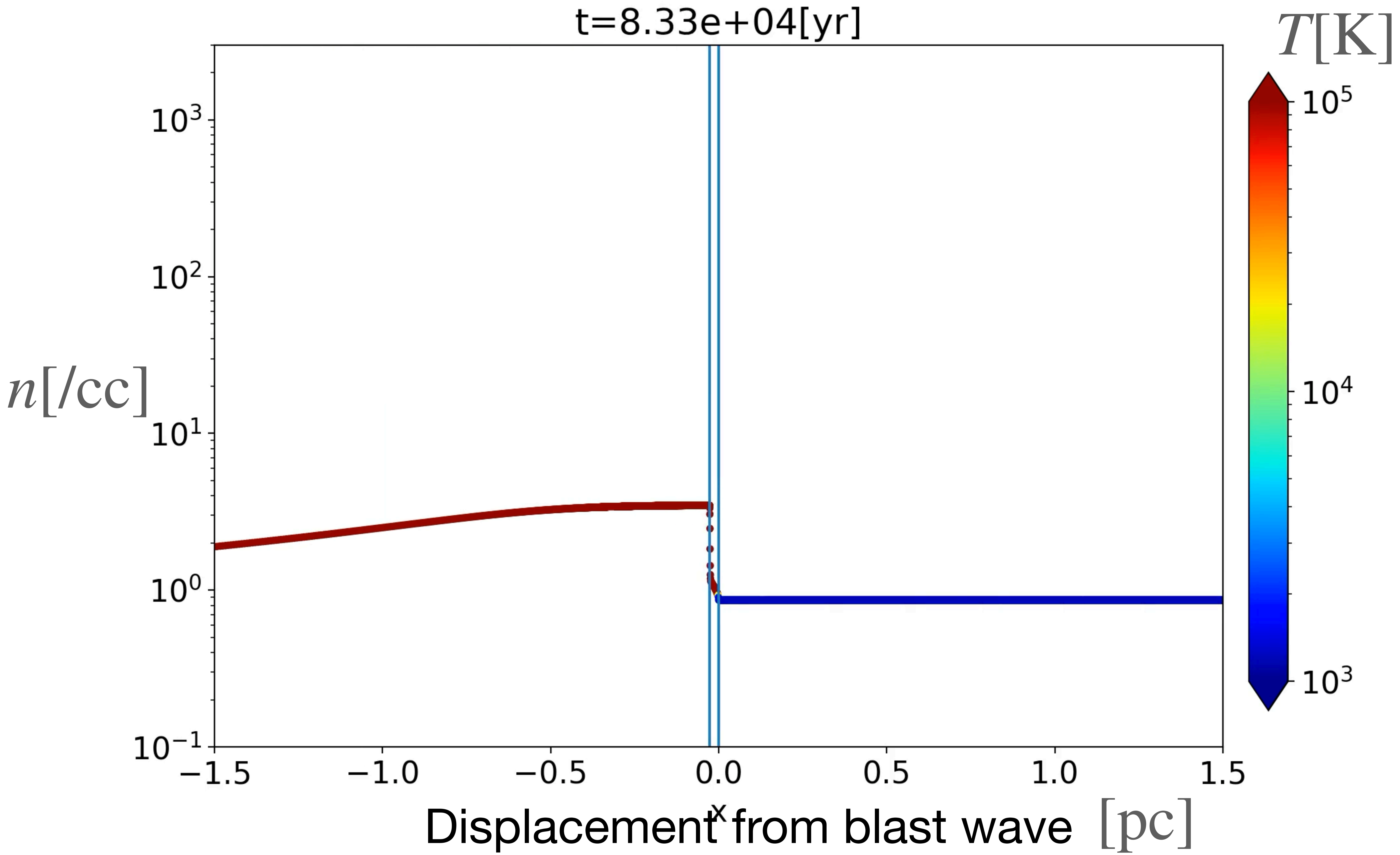
Inutsuka et al.2015

▶ They predicted the presence bubbly structure on galaxy

Simulation result: v,n,p profile



Shell formation and structure



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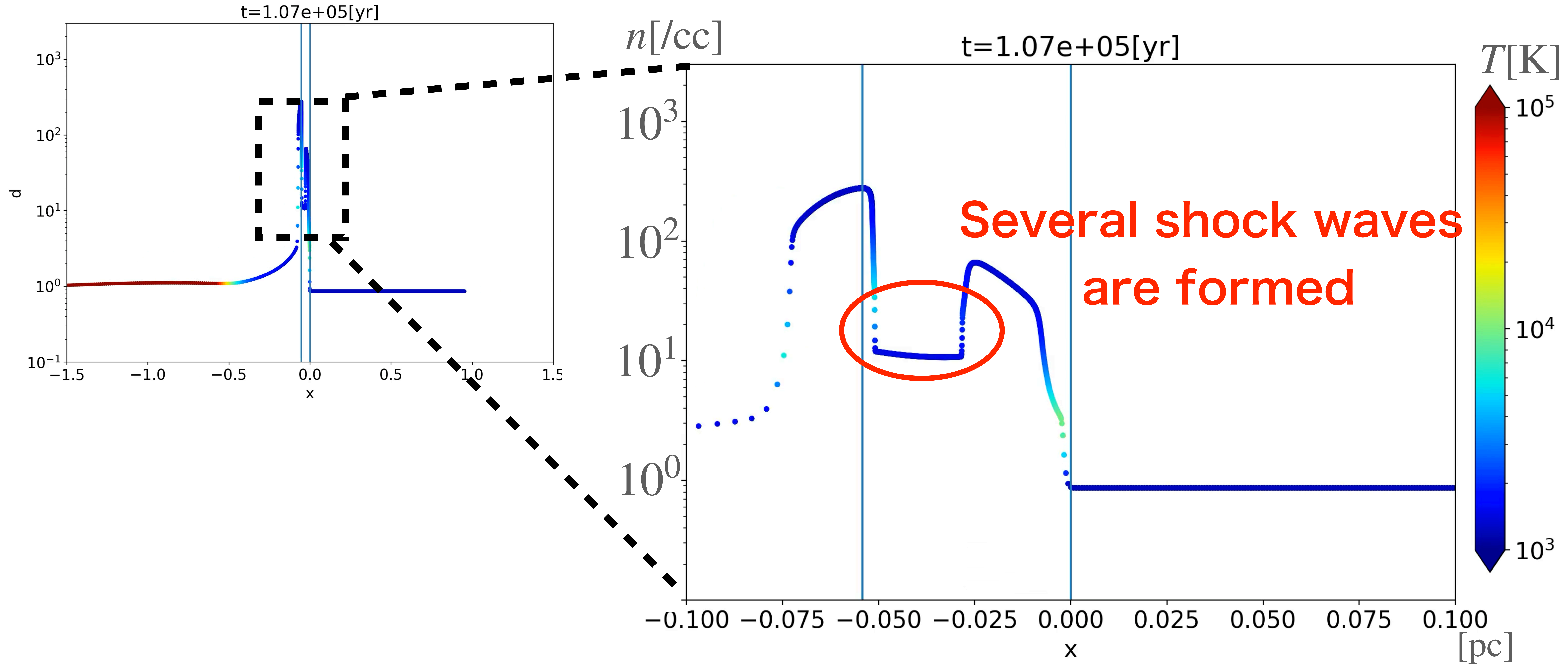

Shell formation and structure