PhD Students' day

Thesis :

Study

of the Vishniac Instability (V.I.)

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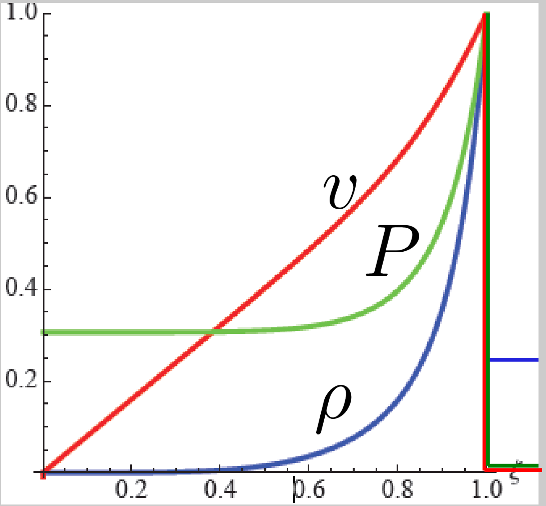
INTRODUCTION

Supernova remnants (SNR)

SNR 0509-67.5 : 400 yrs

NASA, ESA, J. Hester, A. Loll (ASU)

Sedov phase profiles



Simeis : 38000 yrs

Digitized sky Survey, ESA/ESO/NASA FITS Liberator

$R \propto t$ ⟶ $R \propto t^{2/5}$ ⟶ $R \propto t^{1/4\ to\ 3/10}$

Ballistic phase (Truelove & McKee 1999)

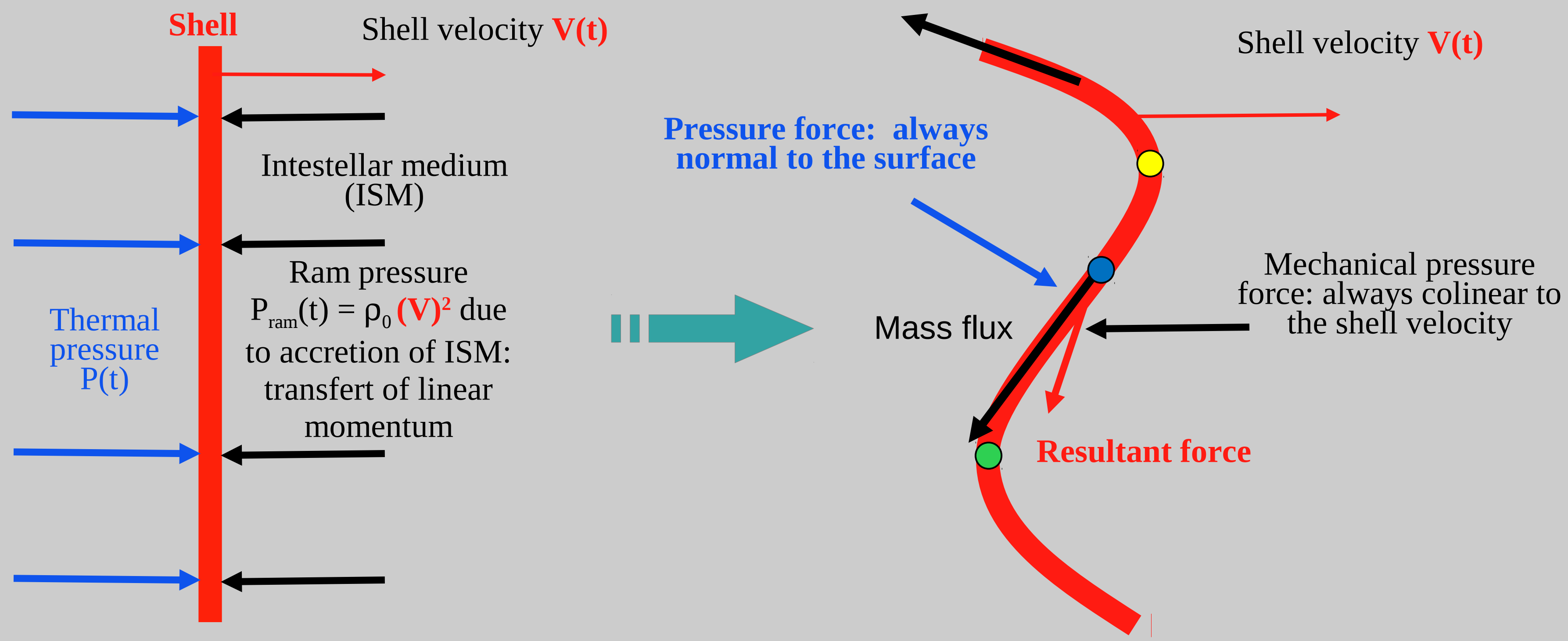
Sedov phase (Sedov 1959, Taylor 1950, Von Neumann 1947)

Radiative phase (Woltjer 1972, Cioffi 1988, Oort 1951)

Ejected matter from supernova: blast wave (BW) expanding in the interstellar medium (ISM).
Apparition of complex structures and filamentation.
Hydrodynamic instabilities.

Mechanism of the Vishniac instability
(Vishniac 1983, Ryu & Vishniac 1987)

Plane layer unperturbed | **Perturbed layer**



AIM :

- **Confirm the existence of the V.I.**
- **Clarify the conditions of instability**
- **Remove contradictions, be more realistic**

THEORY

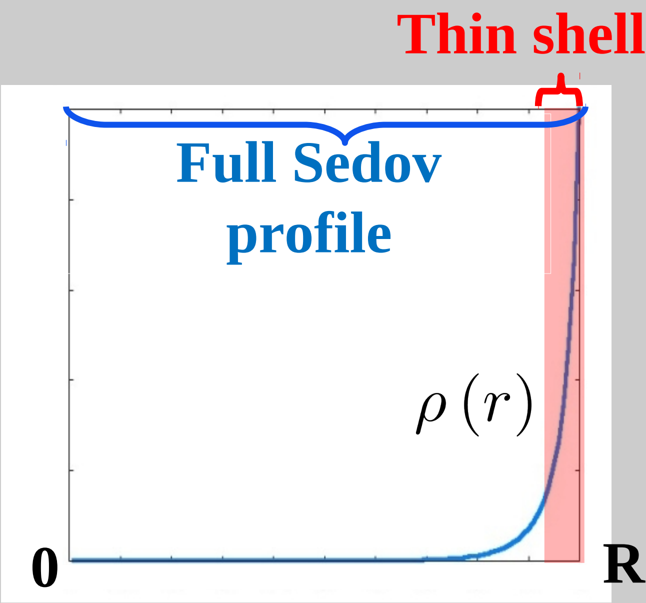
Blast waves and adiabatic index

Mach number: $M \equiv \frac{v_{shock}}{c_{sound}}$. Shock: $M > 1$. Strong shock: $M \gg 1$.

Compression rate: $C \equiv \frac{\gamma+1}{\gamma-1}$ for a strong shock.

$$\gamma \to 1 \implies C \to +\infty$$

Radiative losses in BW → densification behind the shock → C ↗



Small $\gamma \iff$ radiative losses in regard to the density distribution

$$\gamma = 5/3 \Rightarrow C = 4$$
$$\gamma = 1.1 \Rightarrow C = 21$$

Thin shell model: relations of dispersion

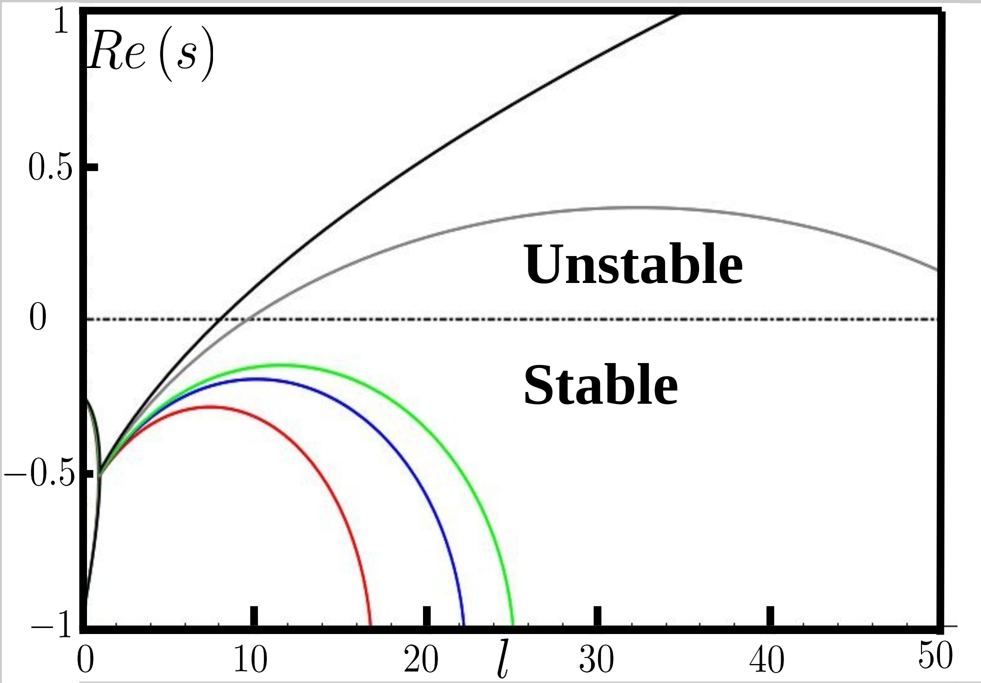
Perturbation : $\delta g \propto t^s$

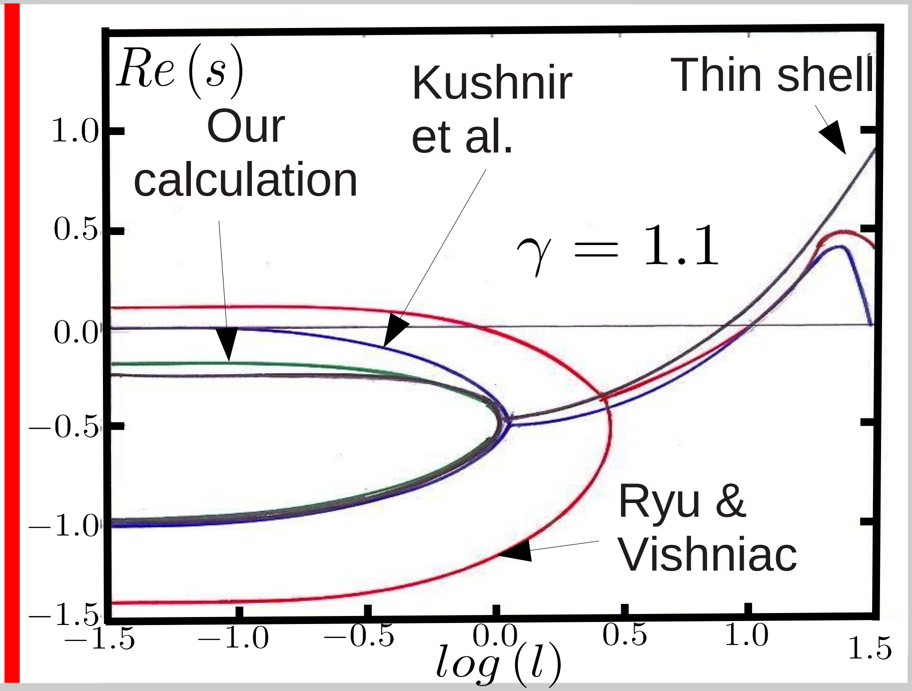
Mode l, growth rate s

$$R \propto t^{2/5}$$

Thin shell model
(Vishniac 1983)

Self-similar flow
(Ryu & Vishniac 1987, Kushnir et al 2005)





$\gamma \to 1$ — $\gamma = 1.1$ — $\gamma = 4/3$ — $\gamma = 7/5$ — $\gamma = 5/3$

Decrease of the growth rate and reduction of the instability domain.
Unstable only for low γ

NUMERICAL SIMULATIONS

Code and workline

HADES 2D : Radiative hydrodynamic code (H.C. Nguyen, C. Michaut , M. Mancini, L. Di Menza)

- Adapted to multi-processor computing
- Planar, cylindrical and spherical geometry
- Euler equations
- Time splitting method, finite volume
- Possibility of losses of energy by cooling function
- Or radiative transfer
- Run on Mesopsl (1472 cores max, 144 for our simulations)

<u>Workline :</u>

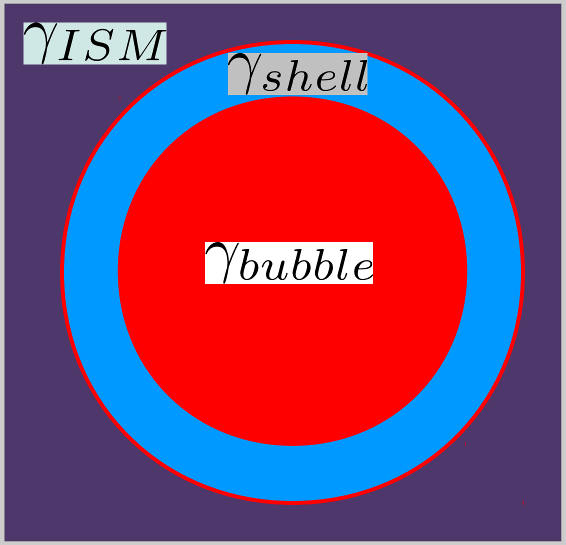
SNR in Sedov phase
Perturbation of non-cooling SNRs
Study of cooling unperturbed SNRs
Perturbation of cooling perturbed SNRs

Previous work

Parametric studies: influence of

- **Adiabatic index**
- **Mach number**
- **Perturbation mode**
- **Amplitude of the perturbation**

(Cavet et al. 2009; Cavet et al. 2011; Michaut et al. 2012; Cavet, PhD Thesis)



No radiative losses in these studies

Radiative effects taken into account by varying γ:

$$\gamma_{ISM} = \gamma_{bubble} = 5/3$$

γ_{shell} variable

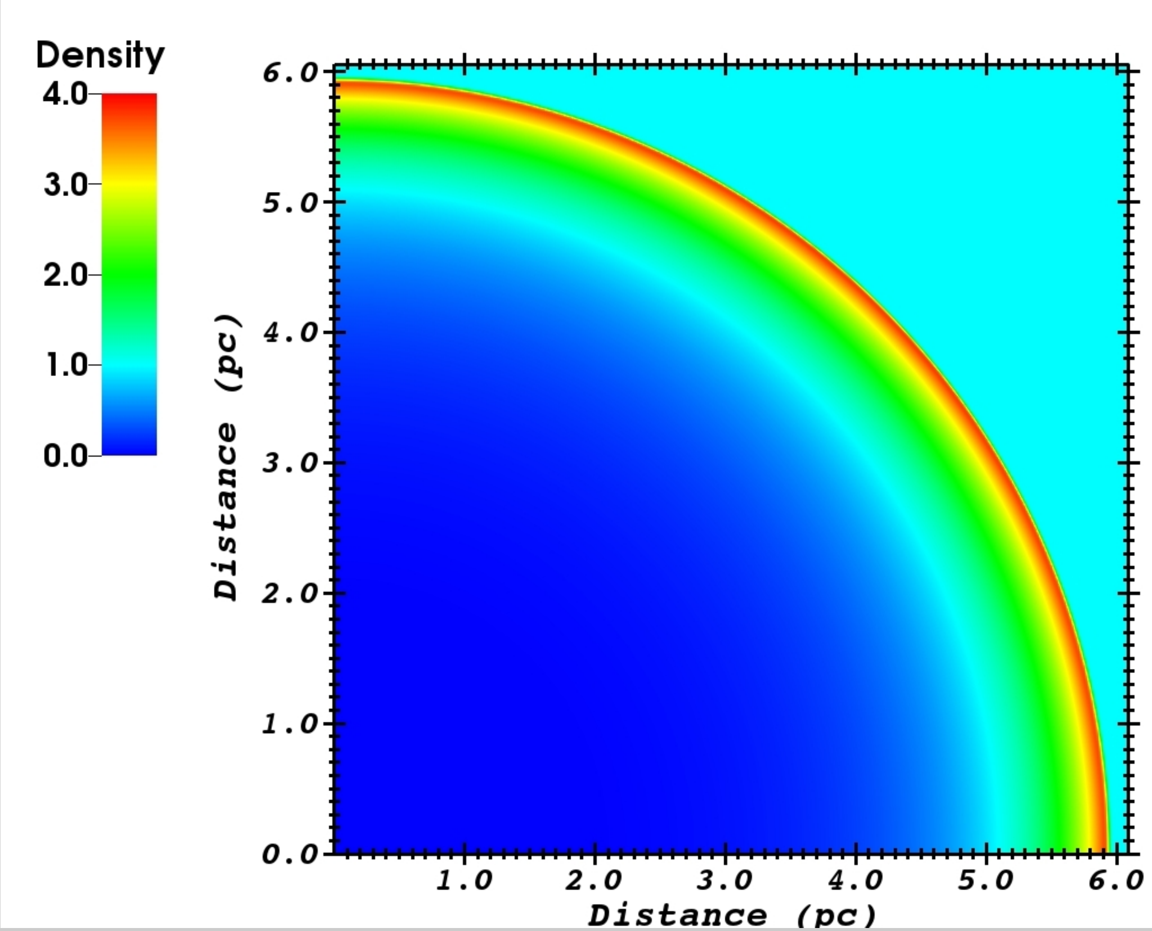
Conclusion: the perturbation is always vanishing in these conditions.

Our aim :

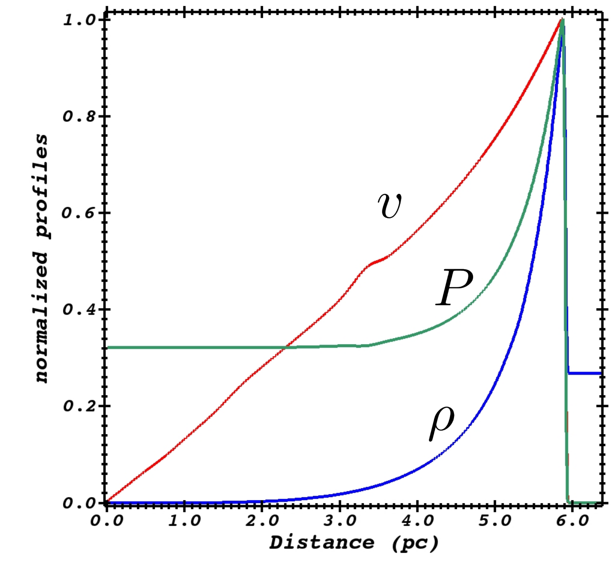
- High resolution
- Closer to theory: uniform adiabatic index γ
- Study of SNRs experience radiative losses (cooling function)

SNR initialization and perturbation

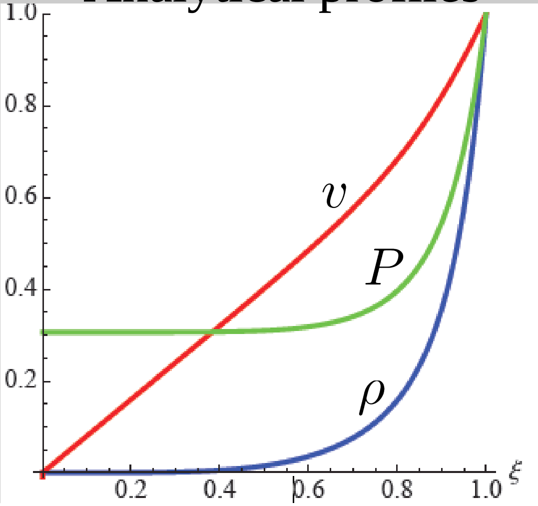
- Isotropy
- Compression rate



Numerical profiles



Analytical profiles



SNR initialisation and perturbation

- Isotropy
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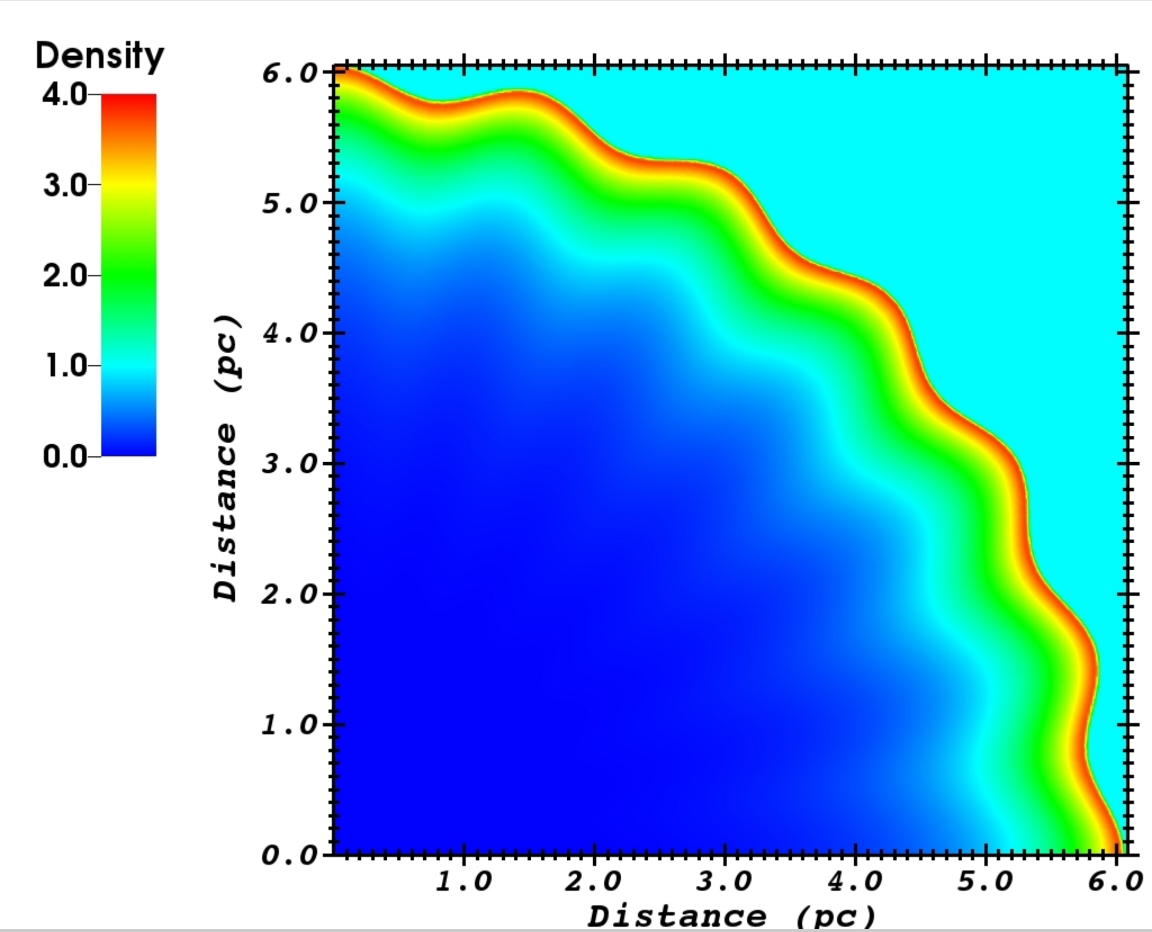
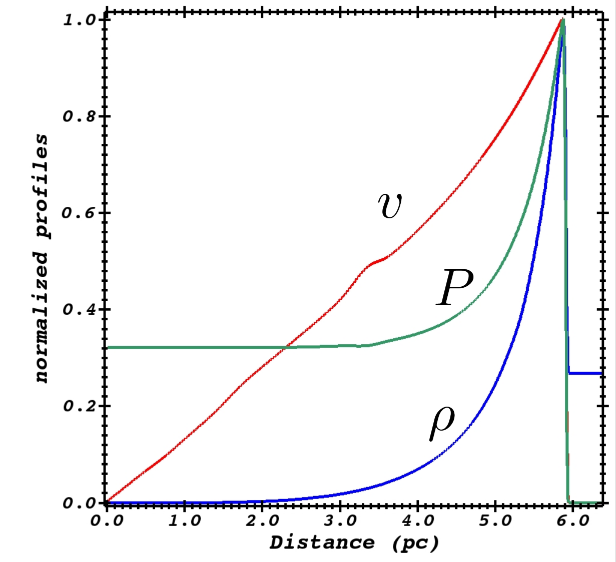
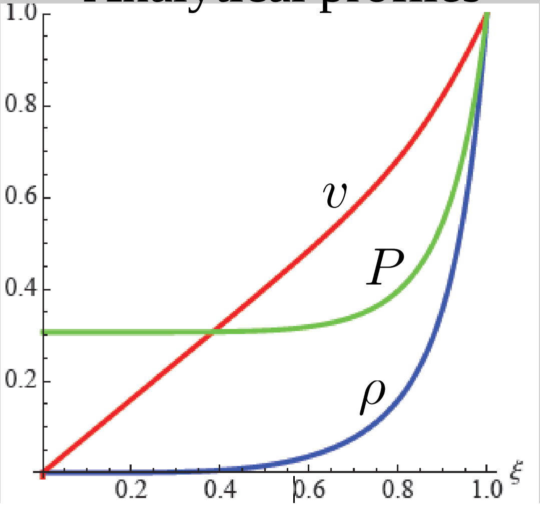


Numerical profiles

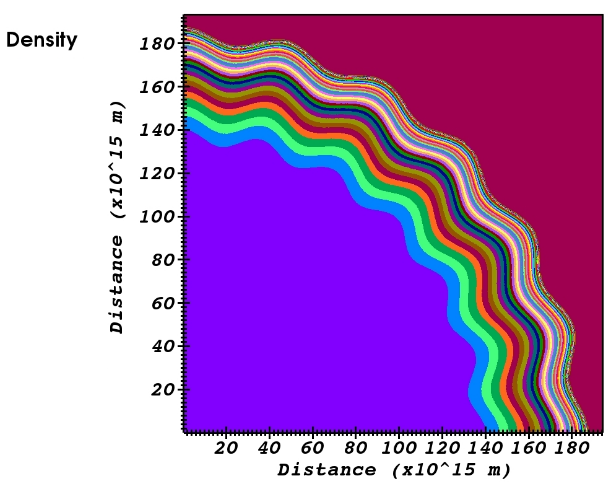


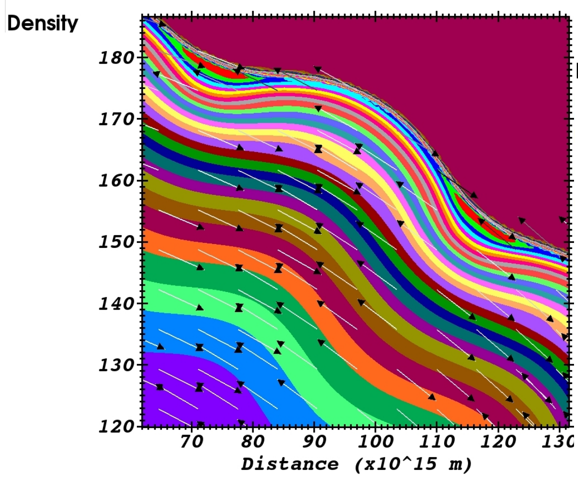
Analytical profiles

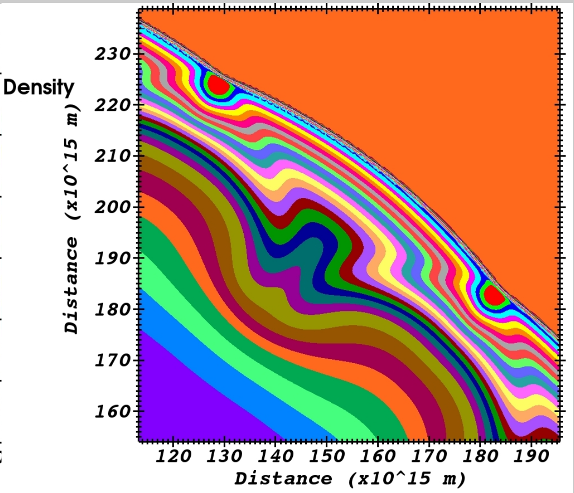


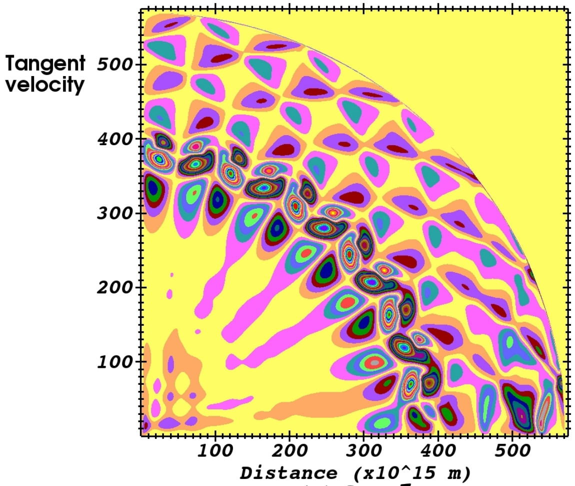
V.I. Without cooling: mechanism and attenuation $\gamma = 5/3$

$t \approx 3\ kyrs$ $t \approx 4\ kyrs$ $t \approx 7.5\ kyrs$

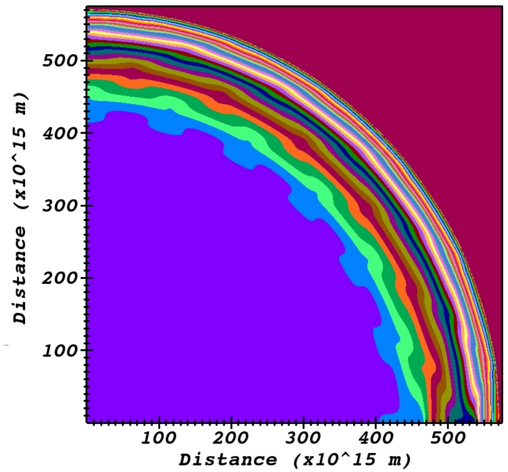








$t \approx 53\ kyrs$

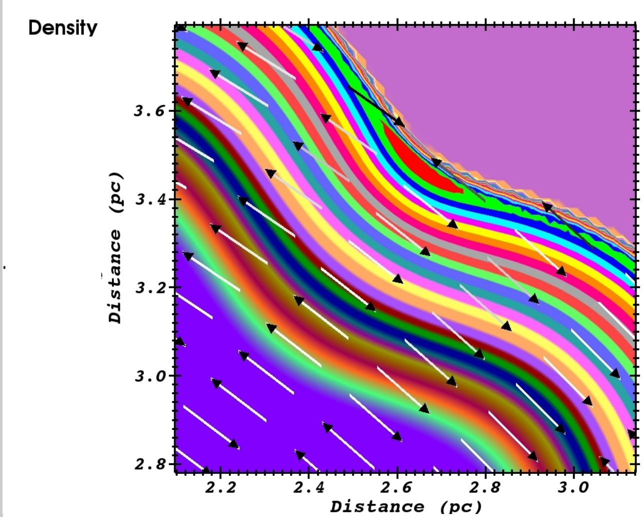


$t \approx 53\ kyrs$

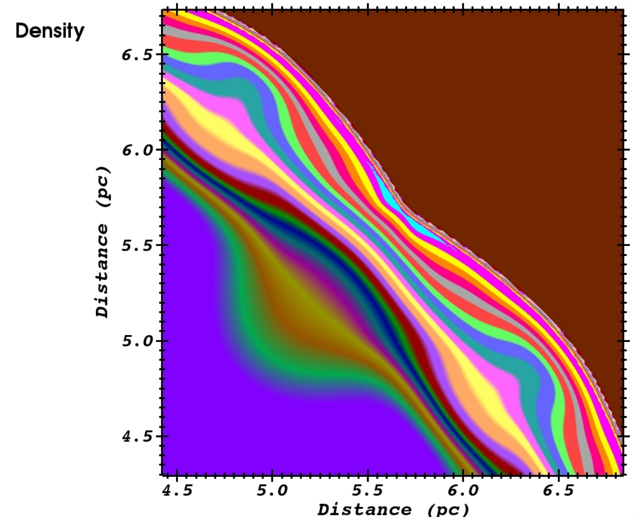
Attenuation of the perturbation, as predicted by the theory. Traces of the V.I. remain at late times.

V.I. without cooling: growth of the perturbation $\gamma = 1.1$

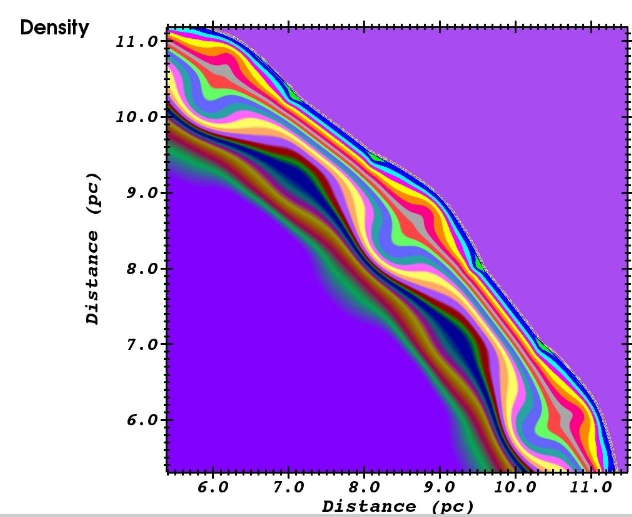
$t \approx 4 kyrs$

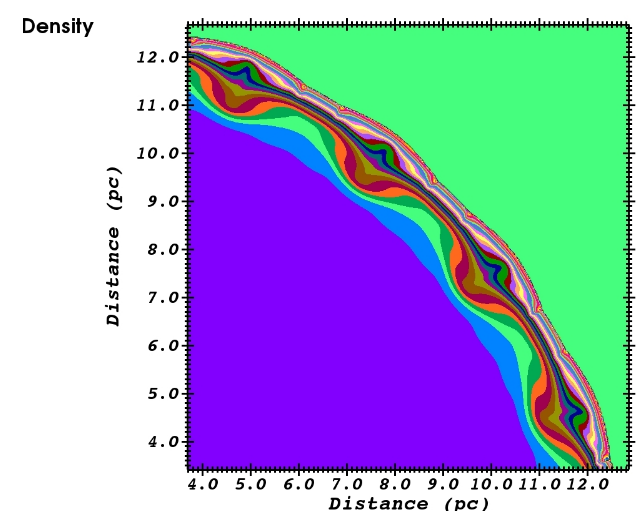


$t \approx 18 kyrs$

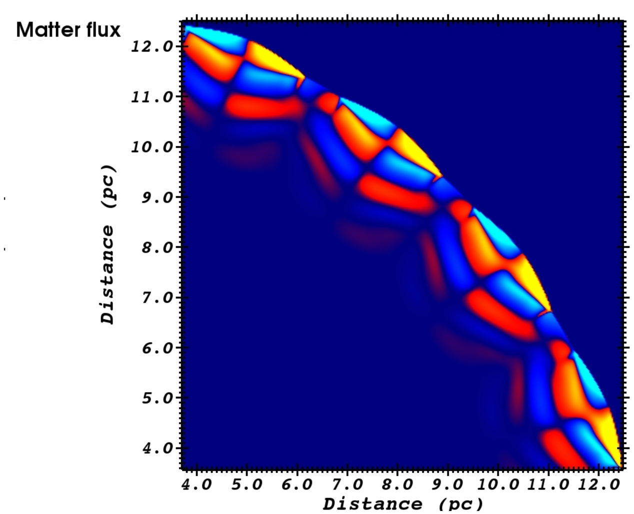


$t \approx 53 kyrs$





$t \approx 200\ kyrs$

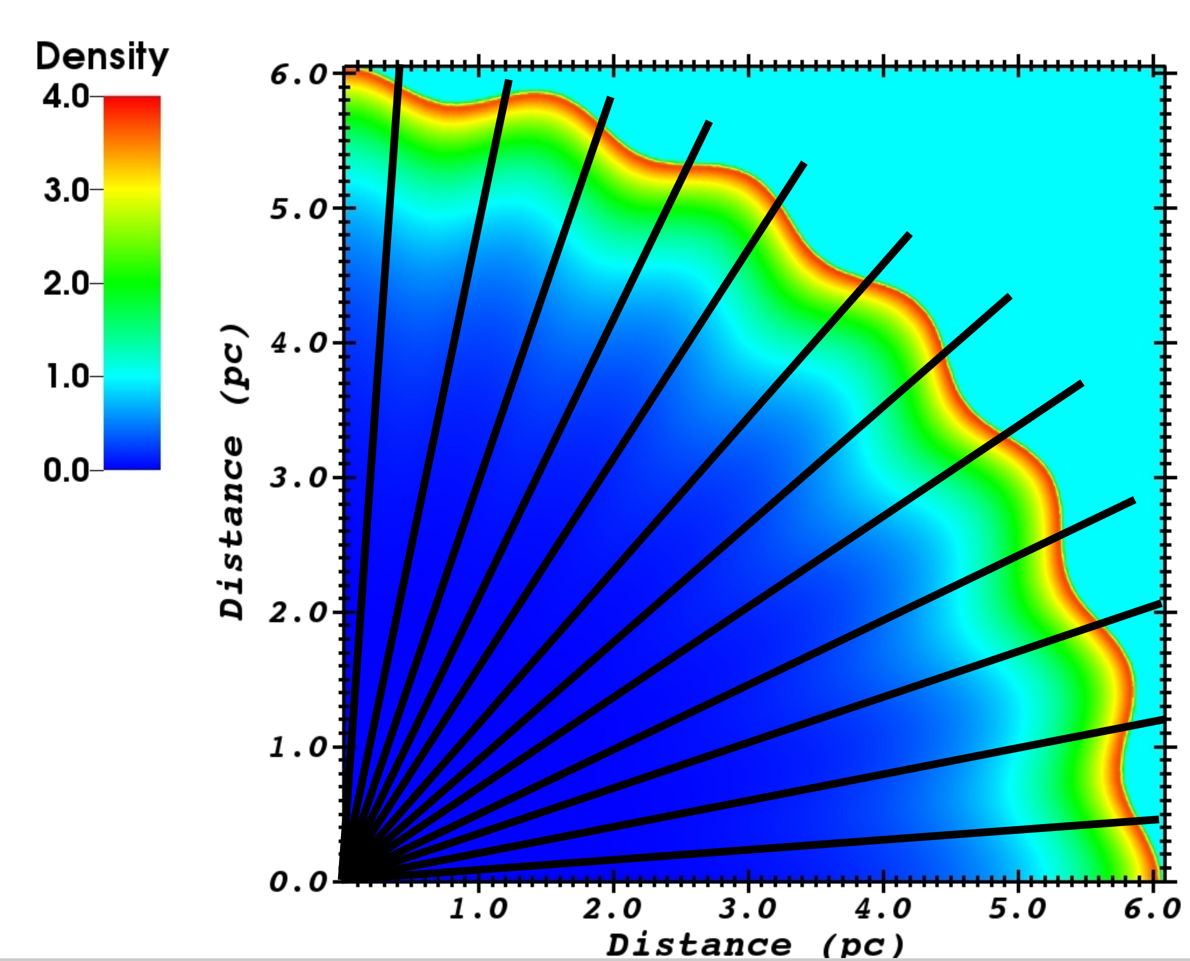


$t \approx 200\ kyrs$

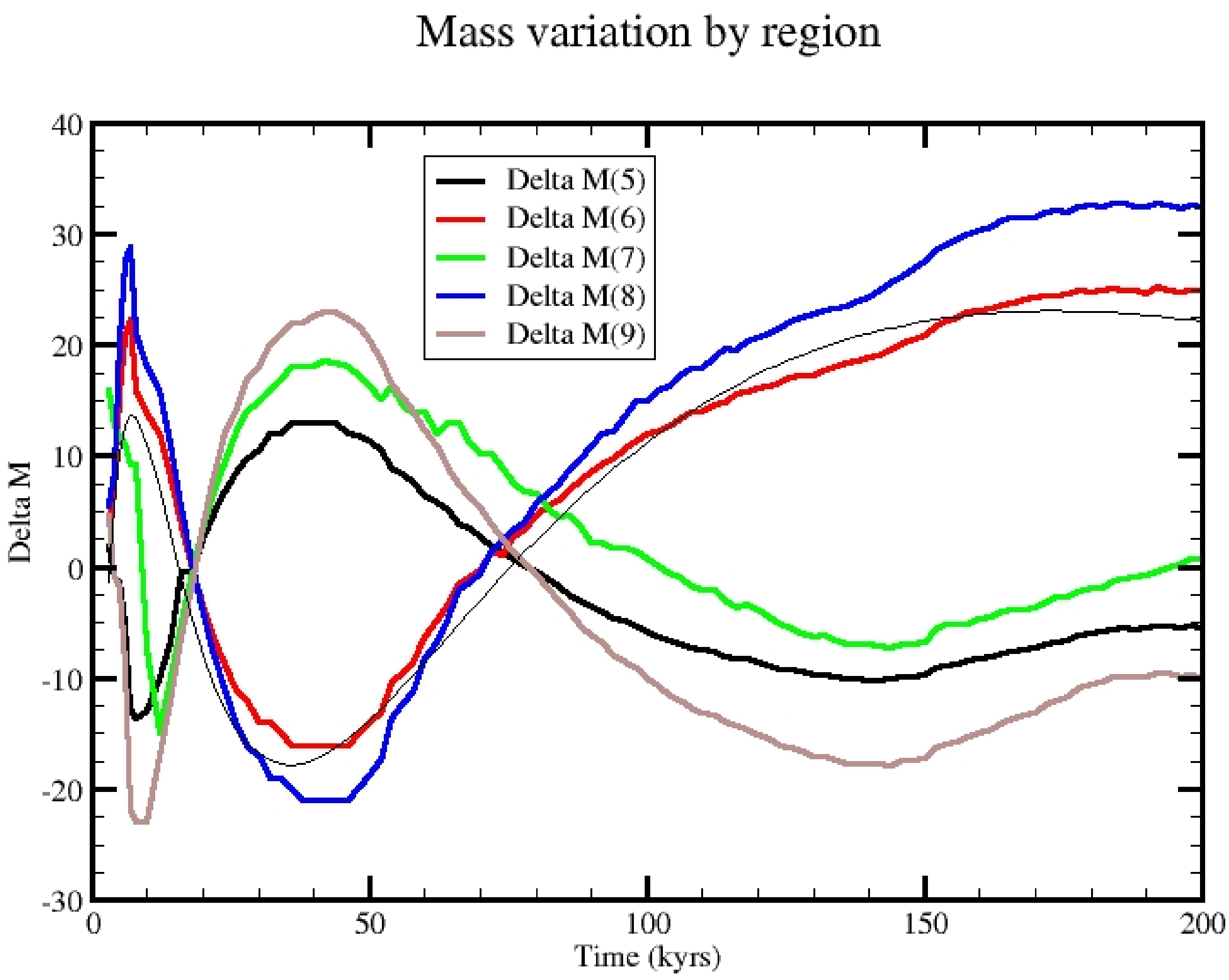
Perturbation still present at late times. V.I. mechanism still acting after $200\ kyrs$

Mass variation: definition

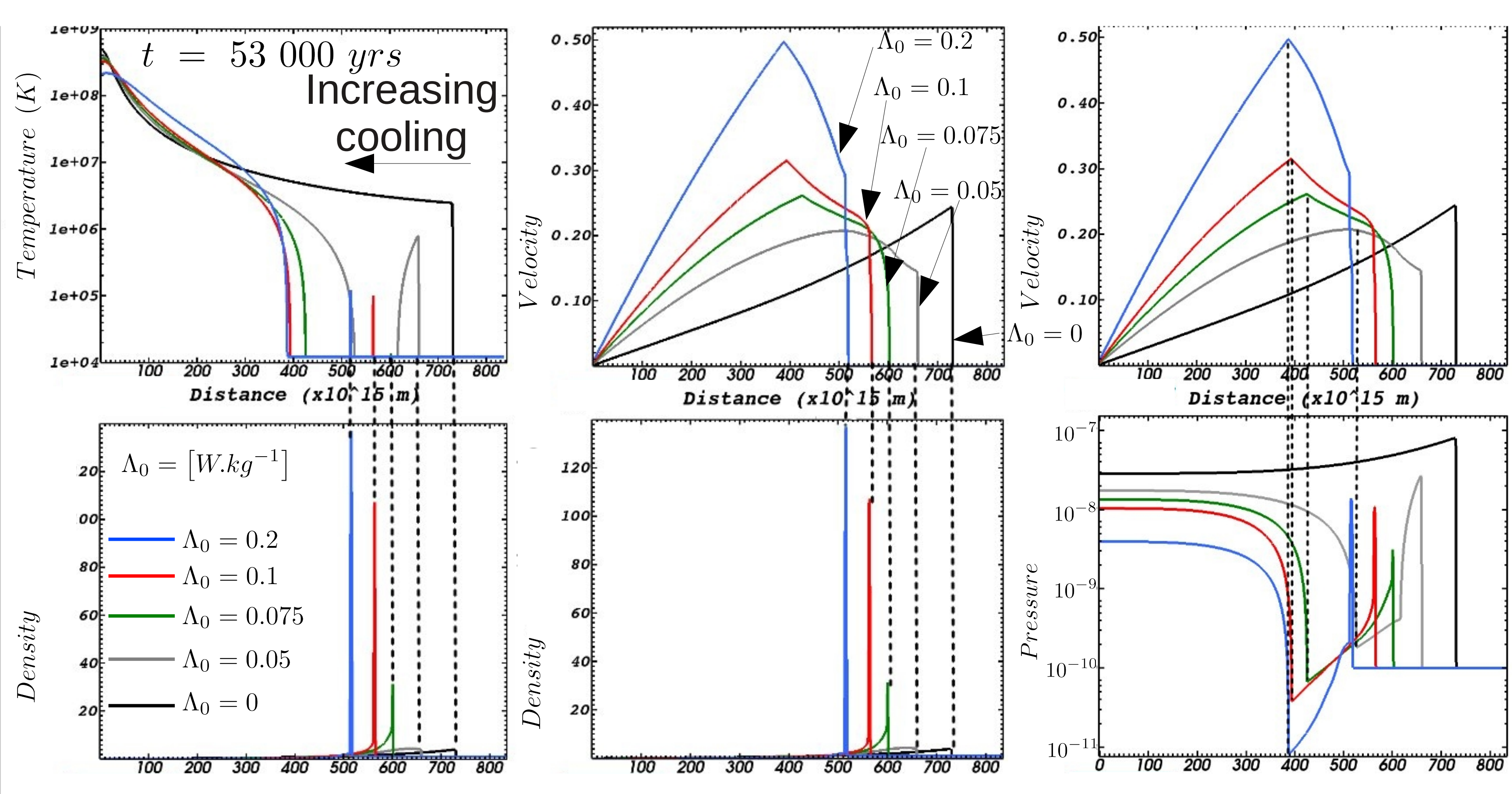
$$\delta M \equiv \frac{M_{perturbed\ region} - M_{unperturbed\ region}}{M_{SNR}}$$



V.I. without cooling: mass variation



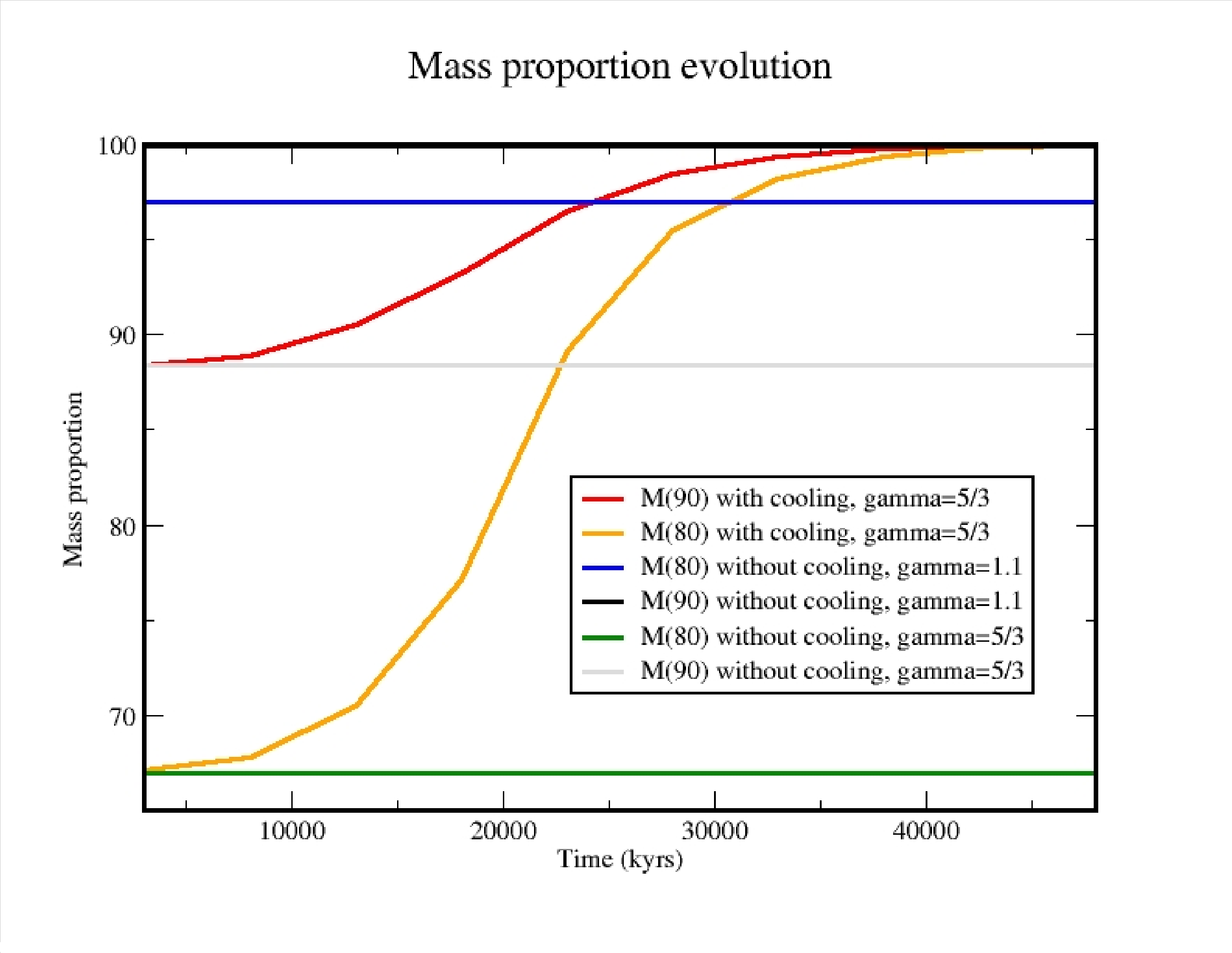
Cooling SNRs



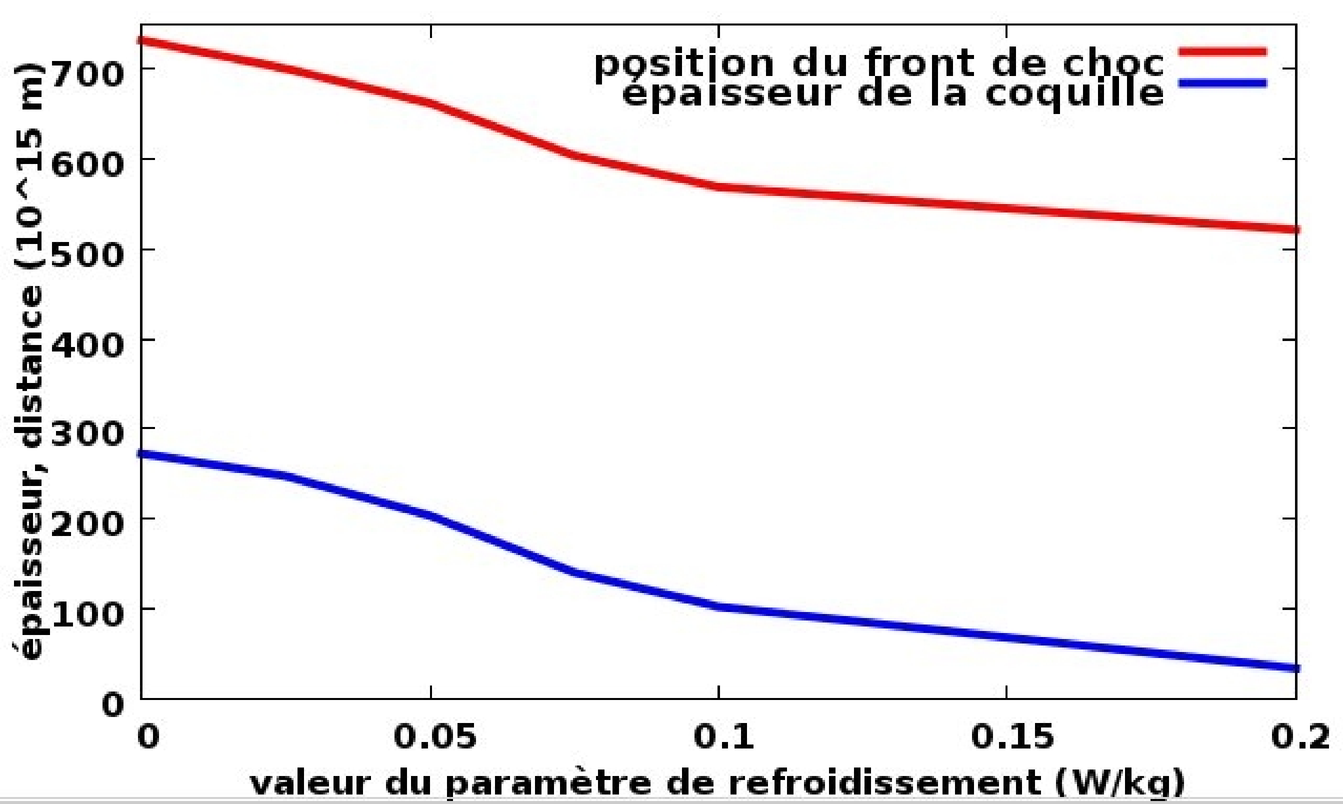
Energy losses → densification and reduction of thickness (⇔ γ→ 1 without Λ in theoretical studies).

Densification and thin shell structure of cooling SNRs

$$M\left(X\%\right) \equiv M\left(X\% \times R_{SNR} < r < R_{SNR}\right)/M_{SNR}$$



Thin shell structure and power-law of expansion of cooling SNRs



Established regime: $R \propto t^{3/10}$ (as Cioffi 1988)

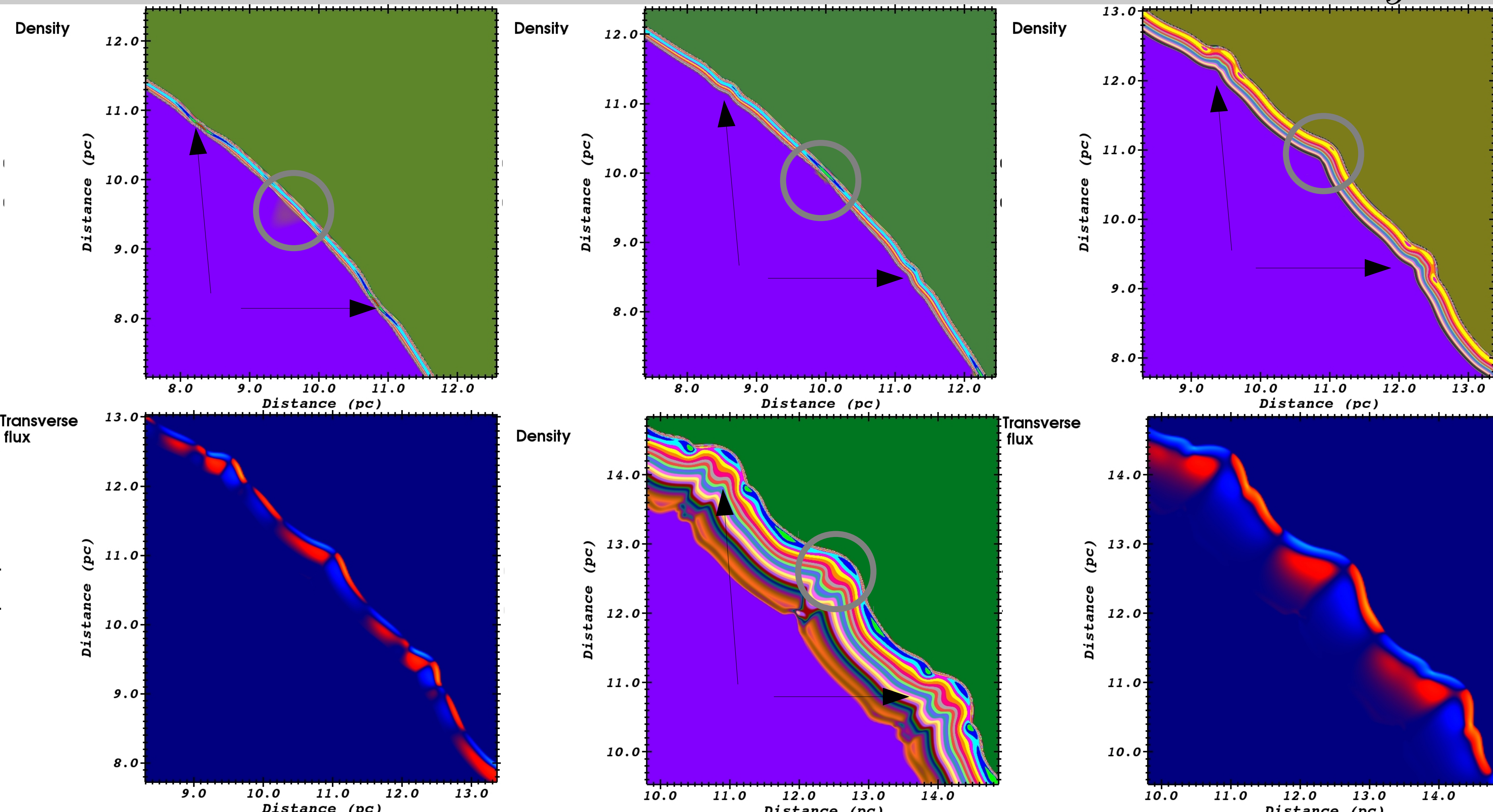
tested with

$$\Lambda = \Lambda_0 \rho$$
$$\Lambda = \Lambda_0 \rho^2$$
$$\Lambda = \Lambda_0 \rho \times t^{2n-3}$$

V.I. in cooling SNRs : double mode generation

$$\gamma = 5/3 \qquad \Lambda = 0.1\rho$$

$t \approx 38\ kyrs$ $\qquad$ $t \approx 43\ kyrs$ $\qquad$ $t \approx 58\ kyrs$



$t \approx 58\ kyrs$ $\qquad$ $t \approx 93\ kyrs$ $\qquad$ $t \approx 93\ kyrs$

Conclusion

Analytical studies:

- Extension of the theory
- Reduction of the domain of instability, need of radiative losses

Numerical simulations:

- In agreement with theory without cooling for $\gamma = 5/3$
- V.I. mechanism seen for $\gamma = 1.1$ at late times for the first time
- SNRs with cooling : self-similar behavior for radius evolution
- V.I. mechanism seen for cooling SNRs at late times for the first time