

MC formation

Olivier Iffrig

Introduction

Single
supernova

Large scale

Perspectives

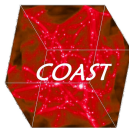
The End

Influence of the large galactic scales on molecular cloud formation

Olivier Iffrig
with Patrick Hennebelle

Service d'astrophysique, DSM/IRFU/SAP

IRFU DDays, July 2nd, 2015



MC formation

Olivier Iffrig

Introduction

Context

Technical issues

Outline

Single
supernova

Large scale

Perspectives

The End

Introduction

About me

MC formation

Olivier Iffrig

Introduction

Context

Technical issues

Outline

Single
supernova

Large scale

Perspectives

The End

Curriculum

- "Classe préparatoire", Lycée Kléber, Strasbourg
- ENS Cachan (physics department, L3 + M1)
- Whole-year internship with Patrick Hennebelle
- M2 "Modélisation et Simulation"

How I got here

- Interests in astrophysics due to L3 / M1 internships
- Strong interests in numerical simulation
- Whole-year internship with Patrick Hennebelle went well

Introduction

MC formation

Olivier Iffrig

Introduction

Context

Technical issues

Outline

Single
supernova

Large scale

Perspectives

The End

Goal

- Study the dynamics of the ISM
- What regulates molecular cloud (and star) formation ?

Means

- MHD simulations
- Gravity + radiative cooling

Why ?

- Goal: understand the observed star formation rates
- Gravity only $\rightsquigarrow SFR_{est} \sim 100SFR_{obs}$
- "Feedback"?

We need to study the effect of feedback processes quantitatively

MC formation

Olivier Iffrig

Introduction

Context

Technical issues

Outline

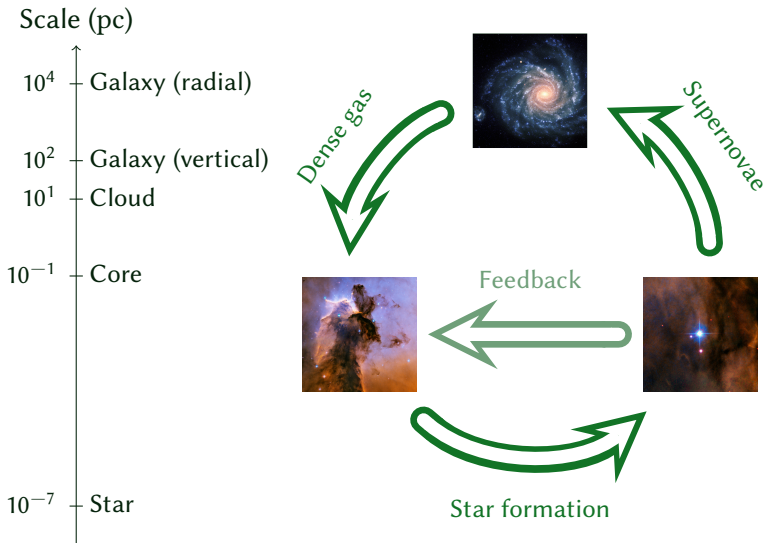
Single
supernova

Large scale

Perspectives

The End

Context



Context

MC formation

Olivier Ifrig

Introduction

Context

Technical issues

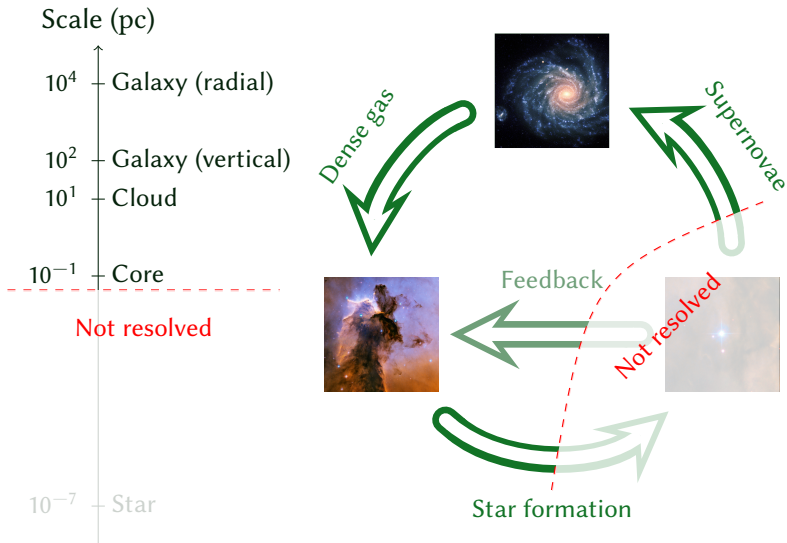
Outline

Single
supernova

Large scale

Perspectives

The End



Context

MC formation

Olivier Ifrig

Introduction

Context

Technical issues

Outline

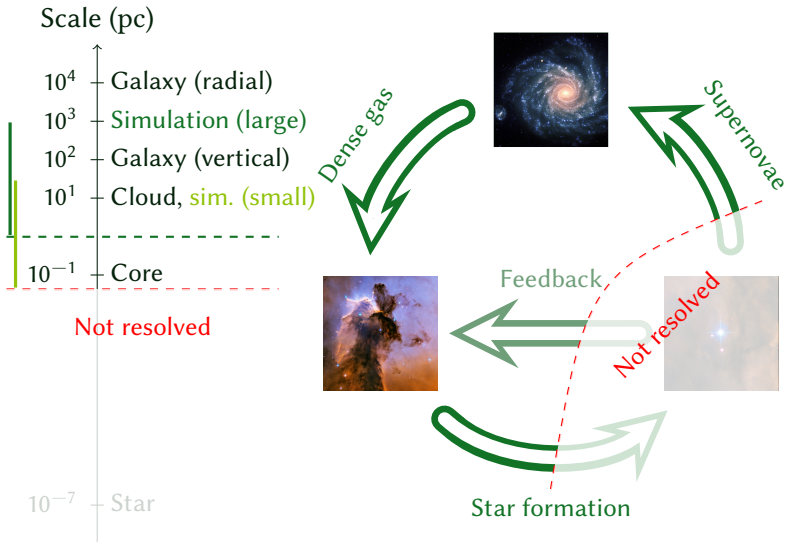
Single

supernova

Large scale

Perspectives

The End



Context

MC formation

Olivier Ifrig

Introduction

Context

Technical issues

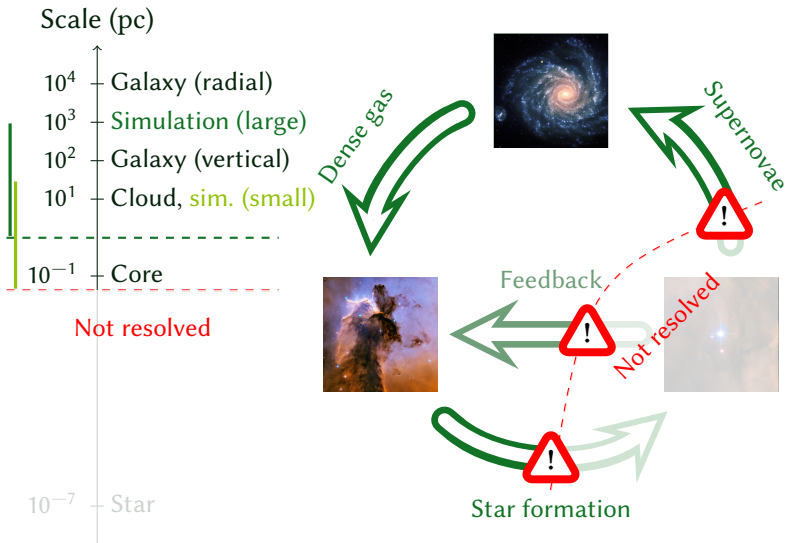
Outline

Single supernova

Large scale

Perspectives

The End



Technical issues

MC formation

Olivier Iffrig

Introduction

Context

Technical issues

Outline

Single supernova

Large scale

Perspectives

The End

Supernovae

- Small-scale simulation
- Model for large-scale simulations

Star formation

- Sink particles
- Depending on resolution: stars or "clusters"
- Positions for feedback sources

Further work: other feedback processes

- Simulations on a relevant scale
- Subgrid models for the large-scale simulations
- Correlation with the formed "stars"

Outline

MC formation

Olivier Iffrig

Introduction

Context

Technical issues

Outline

Single
supernova

Large scale

Perspectives

The End

1. Introduction

2. Impact of a single supernova event on the ISM

3. Large scale simulations: the supernova-driven ISM

4. Perspectives

MC formation

Olivier Iffrig

Introduction

Single
supernova

Context

Uniform

The important result

Turbulent runs

Simulations

Results

Conclusion

Large scale

Perspectives

The End

Impact of a single supernova event on the ISM

Context

MC formation

Olivier Iffrig

Introduction

Single
supernova

Context

Uniform

The important result

Turbulent runs

Simulations

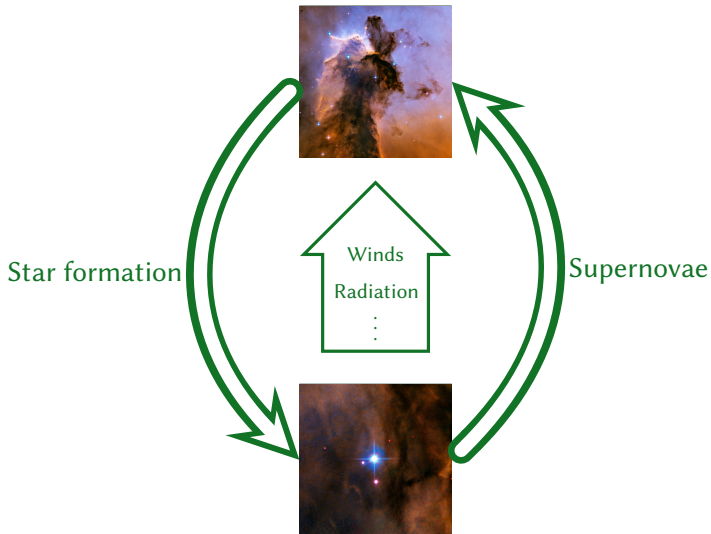
Results

Conclusion

Large scale

Perspectives

The End



Context

MC formation

Olivier Iffrig

Introduction

Single
supernova

Context

Uniform

The important result

Turbulent runs

Simulations

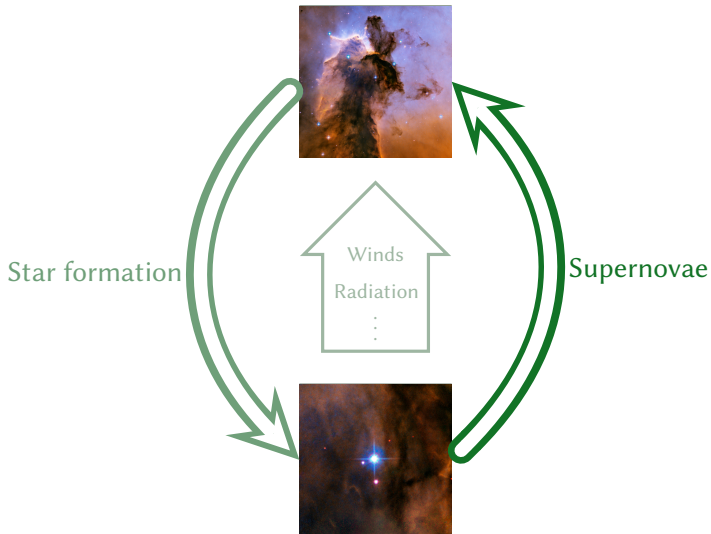
Results

Conclusion

Large scale

Perspectives

The End



MC formation

Olivier Iffrig

Introduction

Single
supernova

Context

Uniform

The important result

Turbulent runs

Simulations

Results

Conclusion

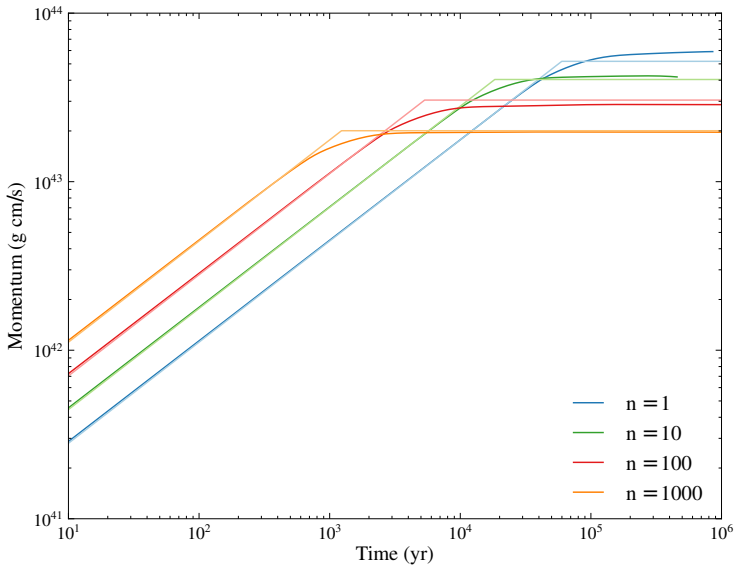
Large scale

Perspectives

The End

Preliminary study: supernova in a uniform medium

The important result



The important result

MC formation

Olivier Iffrig

Introduction

Single
supernova

Context

Uniform

The important result

Turbulent runs

Simulations

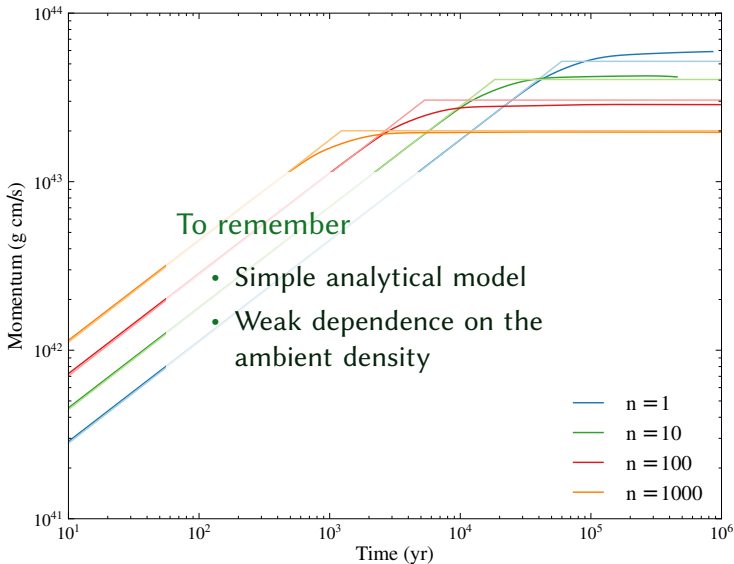
Results

Conclusion

Large scale

Perspectives

The End



MC formation

Olivier Iffrig

Introduction

Single
supernova

Context

Uniform

The important result

Turbulent runs

Simulations

Results

Conclusion

Large scale

Perspectives

The End

Impact of a single supernova on a molecular cloud

MC formation

Olivier Iffrig

Introduction

Single
supernova

Context

Uniform

The important result

Turbulent runs

Simulations

Results

Conclusion

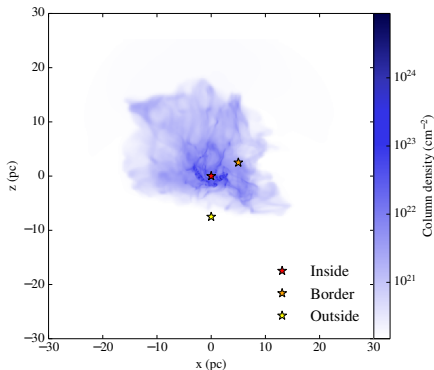
Large scale

Perspectives

The End

Configurations:

- (I) Supernova inside the cloud
- (II) Supernova at the border
- (III) Supernova outside
- (IV) Cloud without supernova



MC formation

Olivier Iffrig

Introduction

Single supernova

Context

Uniform

The important result

Turbulent runs

Simulations

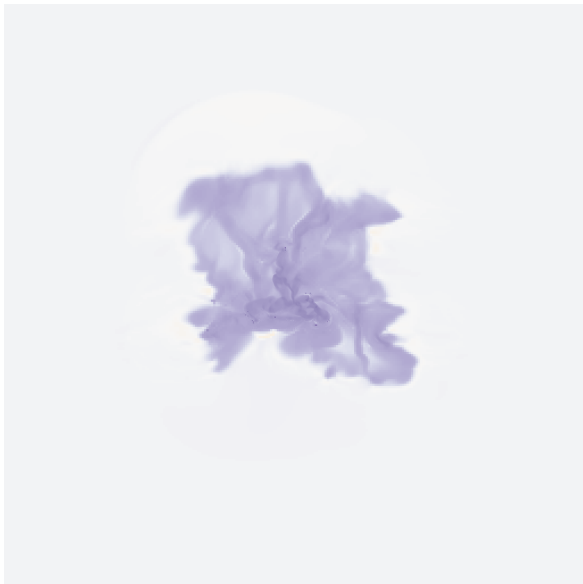
Results

Conclusion

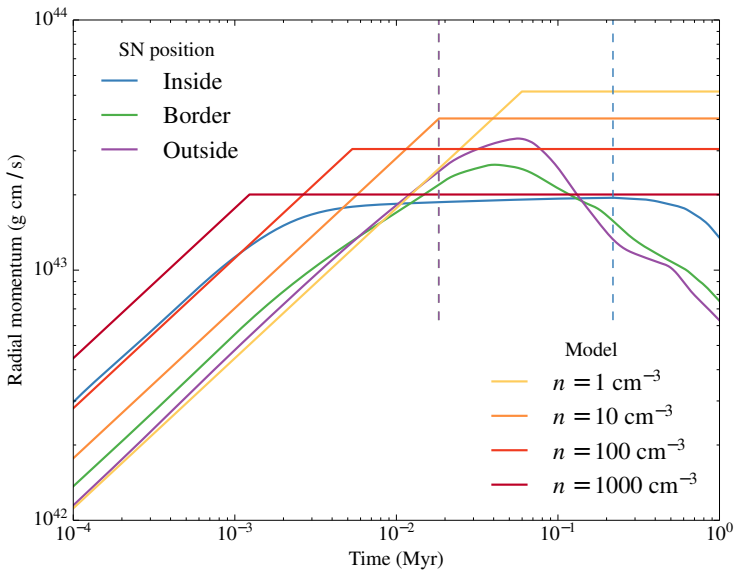
Large scale

Perspectives

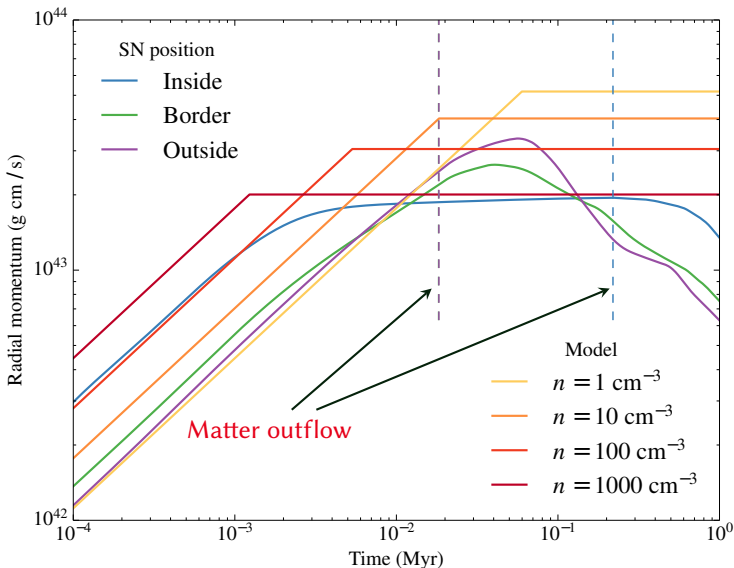
The End



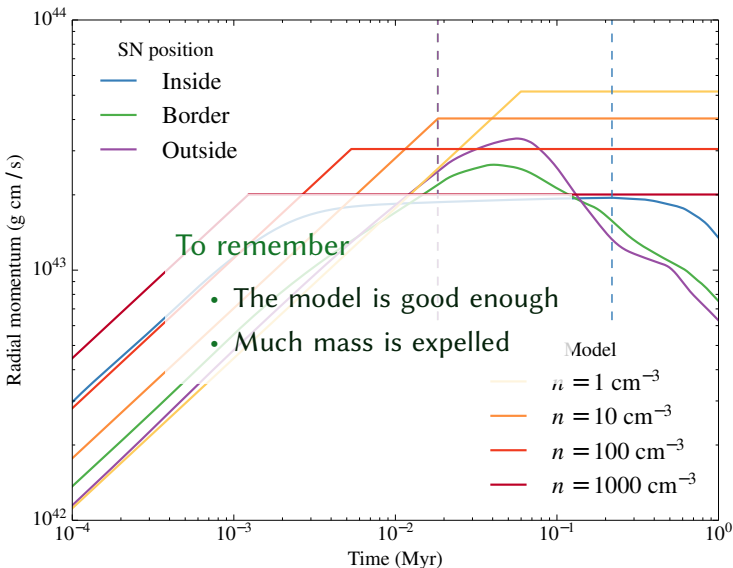
Injected momentum



Injected momentum



Injected momentum



MC formation

Olivier Iffrig

Introduction

Single
supernova

Context

Uniform

The important result

Turbulent runs

Simulations

Results

Conclusion

Large scale

Perspectives

The End

Further statistics

MC formation

Olivier Ifrig

Introduction

Single
supernova

Context

Uniform

The important result

Turbulent runs

Simulations

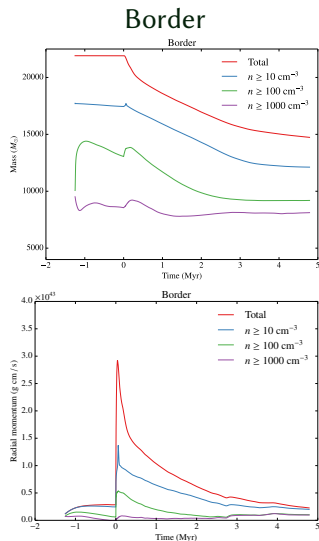
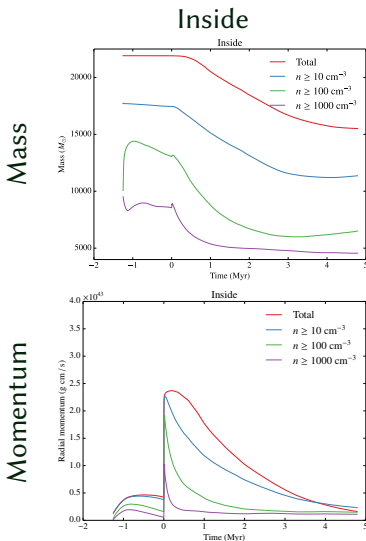
Results

Conclusion

Large scale

Perspectives

The End



Further statistics

MC formation

Olivier Ifrig

Introduction

Single
supernova

Context

Uniform

The important result

Turbulent runs

Simulations

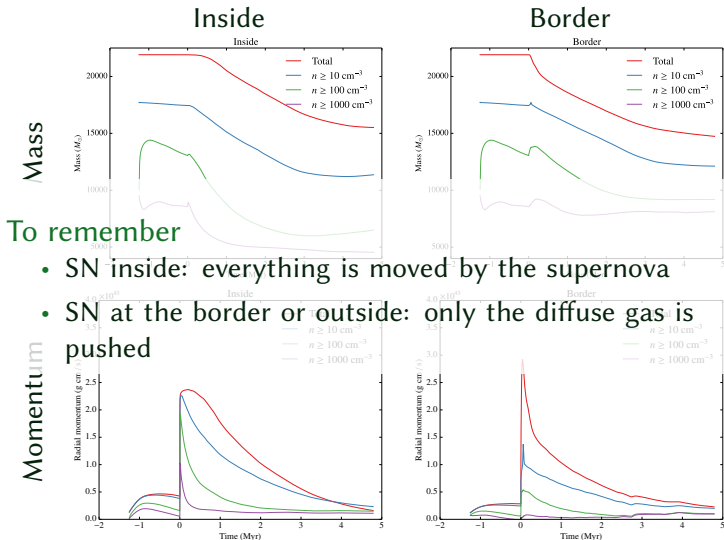
Results

Conclusion

Large scale

Perspectives

The End



MC formation

Olivier Iffrig

Introduction

Single
supernova

Context

Uniform

The important result

Turbulent runs

Simulations

Results

Conclusion

Large scale

Perspectives

The End

We have

- Simple supernova feedback model
- Valid in turbulent magnetized "cloud-like" medium
- Scientific result: supernovae inject momentum into moderately dense medium

But

- The dynamics strongly depend on the location
- The star is able to move and to push the surrounding medium (winds, radiation)

Iffrig & Hennebelle, A & A, 2015, arXiv:1410.7972

MC formation

Olivier Iffrig

Introduction

Single
supernova

Large scale

Context

Visual

Variability

Results

Visual

Star formation

Turbulence

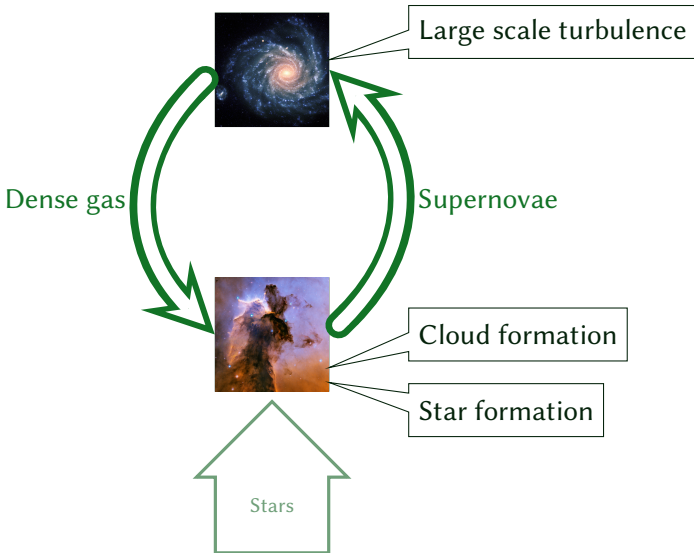
Conclusion

Perspectives

The End

Large scale simulations: the supernova-driven ISM

Context



MC formation

Olivier Ifrig

Introduction

Single
supernova

Large scale

Context

Visual

Variability

Results

Visual

Star formation

Turbulence

Conclusion

Perspectives

The End

Visual

MC formation

Olivier Iffrig

Introduction

Single
supernova

Large scale

Context

Visual

Variability

Results

Visual

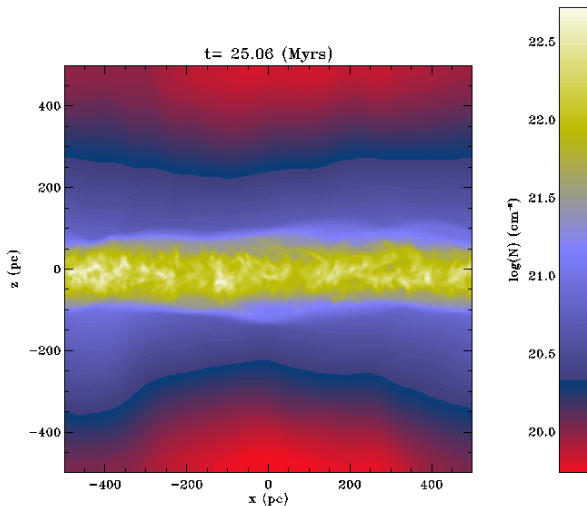
Star formation

Turbulence

Conclusion

Perspectives

The End



Variability with respect to the feedback scheme

MC formation

Olivier Iffrig

Introduction

Single
supernova

Large scale

Context

Visual

Variability

Results

Visual

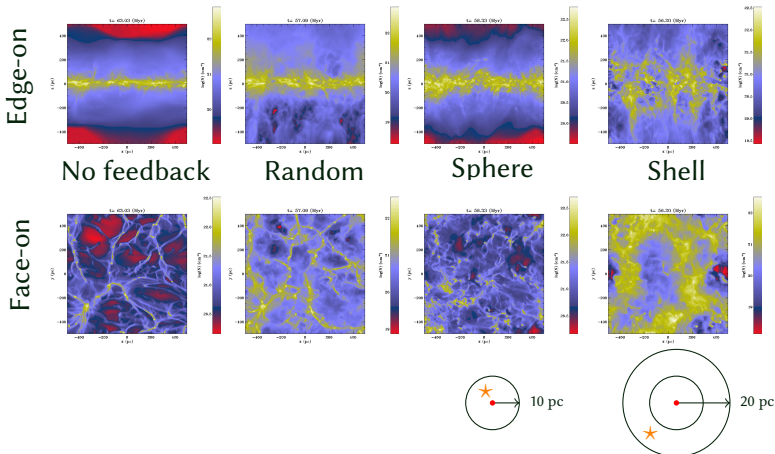
Star formation

Turbulence

Conclusion

Perspectives

The End



Hennebelle & Iffrig, A & A, 2014, arXiv:1405.7819

Variability with respect to the feedback scheme

MC formation

Olivier Iffrig

Introduction

Single
supernova

Large scale

Context

Visual

Variability

Results

Visual

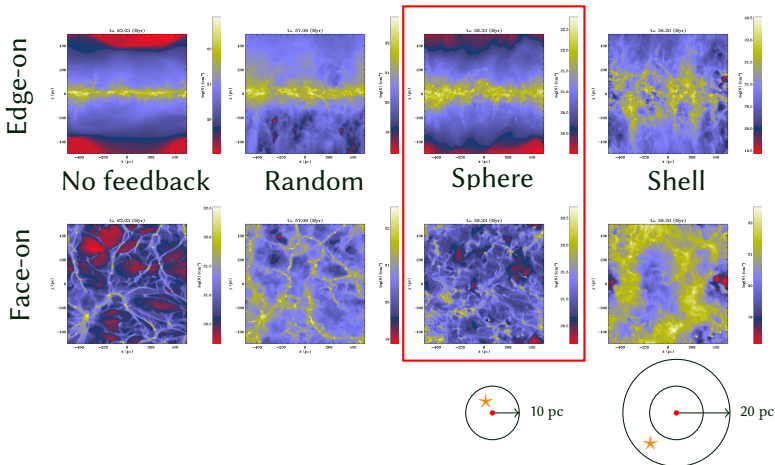
Star formation

Turbulence

Conclusion

Perspectives

The End



Hennebelle & Iffrig, A & A, 2014, arXiv:1405.7819

MC formation

Olivier Iffrig

Introduction

Single
supernova

Large scale

Context

Visual

Variability

Results

Visual

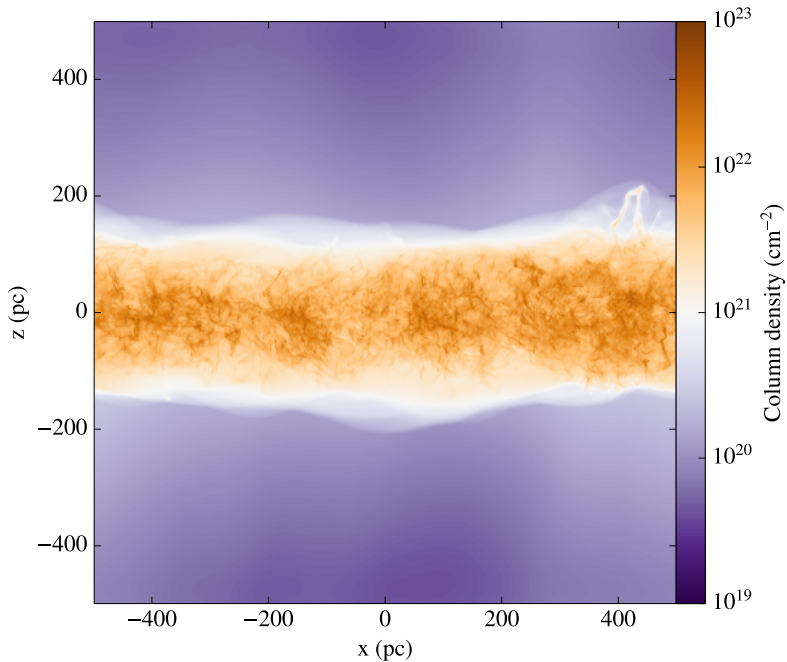
Star formation

Turbulence

Conclusion

Perspectives

The End



Star formation efficiency

MC formation

Olivier Iffrig

Introduction

Single
supernova

Large scale

Context

Visual

Variability

Results

Visual

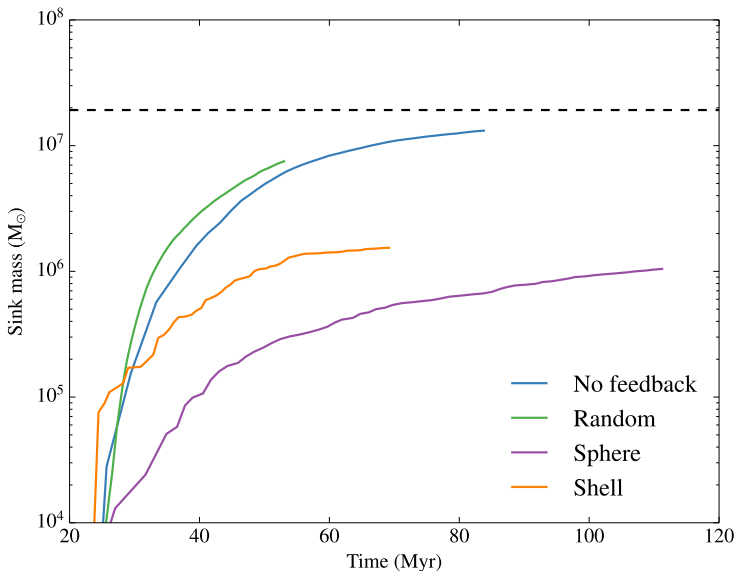
Star formation

Turbulence

Conclusion

Perspectives

The End



Large scale turbulence: 3D

MC formation

Olivier Iffrig

Introduction

Single
supernova

Large scale

Context

Visual

Variability

Results

Visual

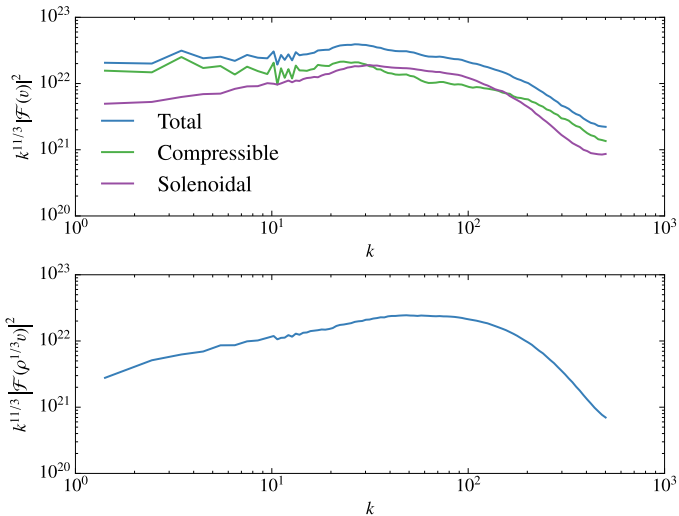
Star formation

Turbulence

Conclusion

Perspectives

The End



Large scale turbulence: 2D

MC formation

Olivier Ifrig

Introduction

Single
supernova

Large scale

Context

Visual

Variability

Results

Visual

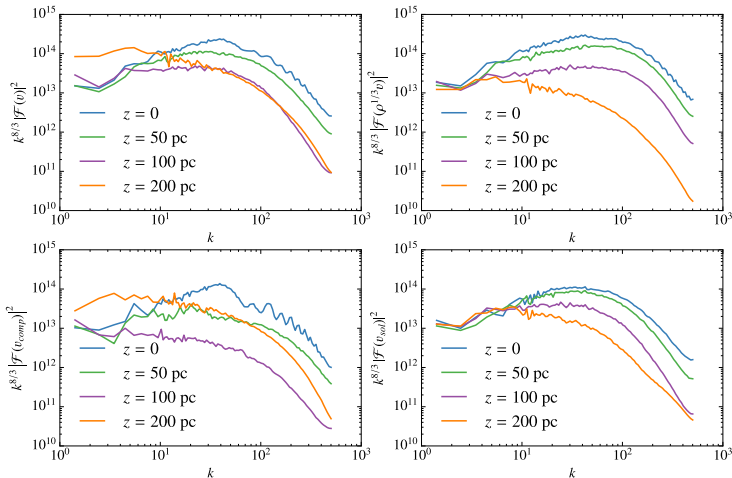
Star formation

Turbulence

Conclusion

Perspectives

The End



Conclusion

MC formation

Olivier Iffrig

Introduction

Single
supernova

Large scale

Context

Visual

Variability

Results

Visual

Star formation

Turbulence

Conclusion

Perspectives

The End

Results

- Sensitivity to the feedback scheme
- Supernova feedback regulates star formation
- It is possible to study large scale turbulence (to a limited extent)

But...

- The subgrid feedback model has to be improved
- We will have to take care of the large scale structure: spiral arms, rotation, ...
- Supernovae are probably not the only relevant process

MC formation

Olivier Iffrig

Introduction

Single
supernova

Large scale

Perspectives

The End

Perspectives

MC formation

Olivier Iffrig

Introduction

Single
supernova

Large scale

Perspectives

The End

Large scale

- Detailed study of the high-resolution data (clump properties, ...)
- Zoom-in simulations

Small scale: more physics

- Winds (work in progress), H_{II} regions (kinetic model)
- Ionization and radiative transfer (S. Geen)
- H₂ chemistry (V. Valdivia)
- Couplings

MC formation

Olivier Iffrig

Introduction

Single
supernova

Large scale

Perspectives

The End

Thanks for your attention!

Single event: Iffrig & Hennebelle, A & A, 2015, arXiv:1410.7972

Large scale: Hennebelle & Iffrig, A & A, 2014, arXiv:1405.7819