Self-propagating star formation in spiral galaxies

Complex system simulation - Group 15

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Introduction

- Galactic structures are traditionally determined by Newtonian dynamics
- Self-propagating star formation (SPSF) : occurs in a differentially rotating disk can produce a stable spiral structure
- the SPSF mechanism could exhibit the critical behaviour of a phase transition

https://scitechdaily.com/complex-mechanics-of-the-evolution-of-the-universe-the-secrets-of-3000-galaxies-laid-bare/

References: The Astrophysical Journal, 223:129-139, 1978 July 1, The Astrophysical Journal, 210:670-678, 1976 December 15

Motivation and hypothesis

Motivation:

- Only using a simple mechanism instead of involving detailed dynamics.

Hypothesis:

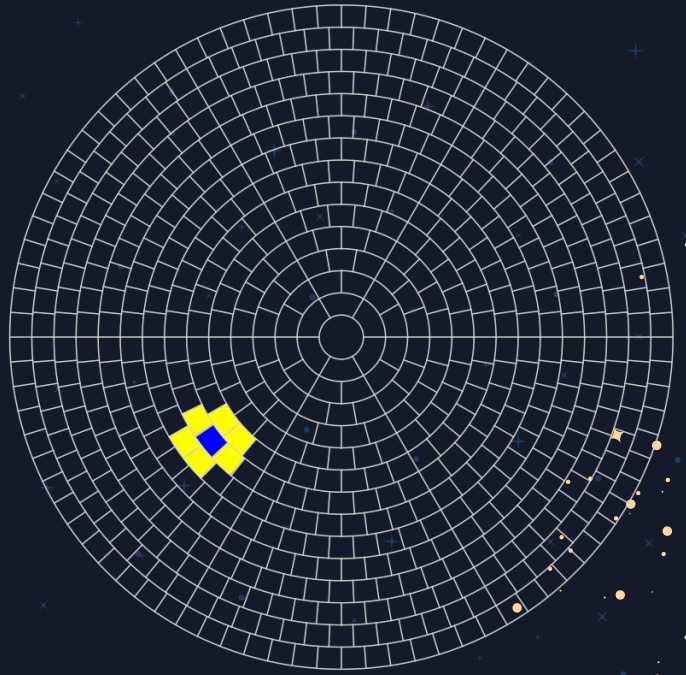
- Based on the self-propagating star formation theory, it invokes percolation phase transition, which gives rise to the formation of spiral patterns in the galaxy. We use ABM to mimic the formation of galaxies, finding the critical probability by phase transition plots and cluster size plots. Different combination of parameters are tested to see if the spiral pattern emerges. We assume that only considering the SPSF mechanism is sufficient for the occurrence of the spiral structure.

Research questions:

- How does the simulated propagation probability affect the spiral pattern?
- When will the percolation emerge and how it affects the spiral pattern?

Our model

- Random cellular automaton
- Each cell is a potential star formation region
- A star formation (blue) can induce neighbouring regions (yellow)
- Differential rotational occurs in each ring → different neighbours at each timesteps
- Local communication



Code can be found on Github: https://github.com/cpiwong/Complex-System-Simulation

Grid properties

- Grid has **N** rings
- Each ring has **n** number of cells
- Each ring has velocity **1/r**
- Each cell (star) goes through three stages at each timestep, born (brightest) → gets old → dies(dimmest)
- Spontaneous star forms throughout the grid randomly

$$n_{cells} = \sum_{x=1}^{N_{rings}} xr$$

Method

Parameters:

A. Initial number of stars

B. Regeneration time

C. Propagation speed

D. Maximum random stars

E. Probability of propagation

Experiment 1:

- run the simulations with different propagation probability (p=0.1 to 0.6)

Experiment 2:

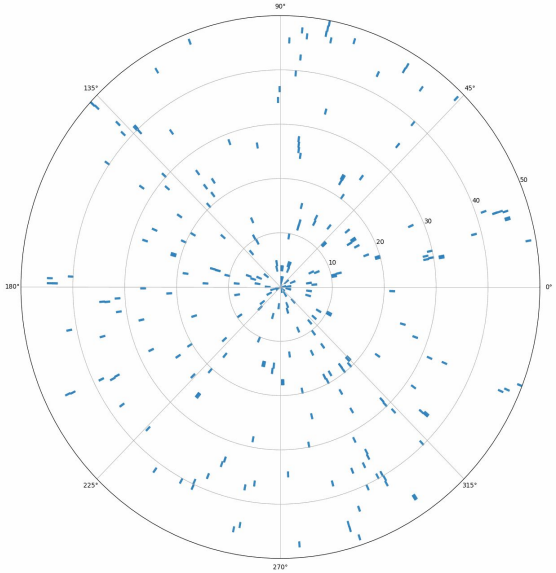
- a total of 64 simulations with 3 different parameter combinations (A,B,C)

Experiment 3:

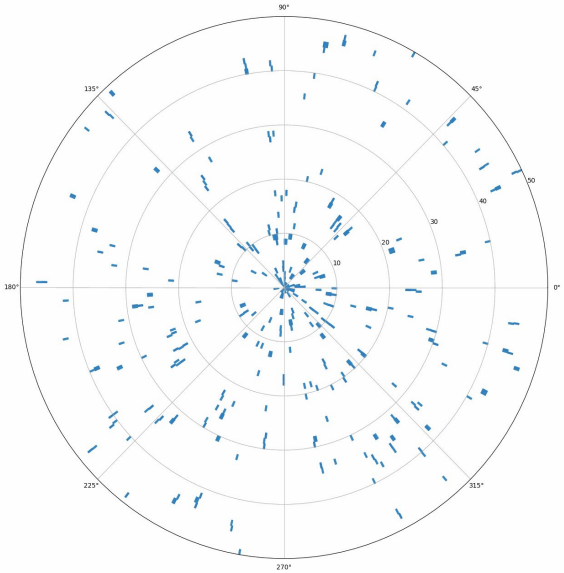
- change the grid size to obtain cluster sizes for percolation

Results: Different phases

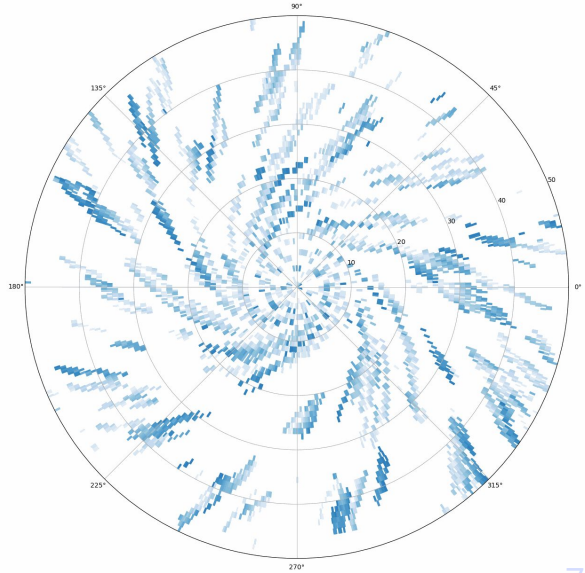
Phase 1: no propagation
P = 0.05



Phase 2: propagation
P = 0.15

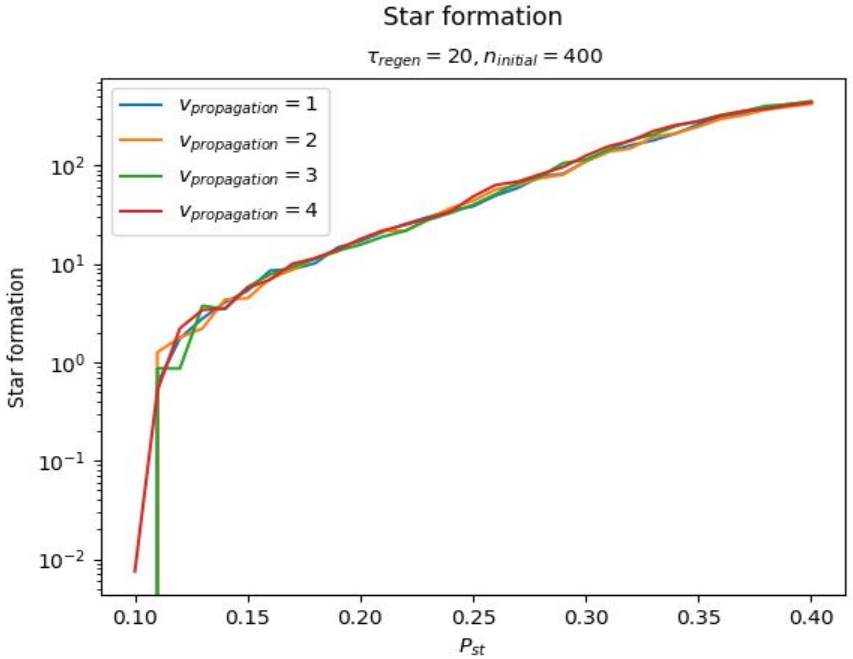


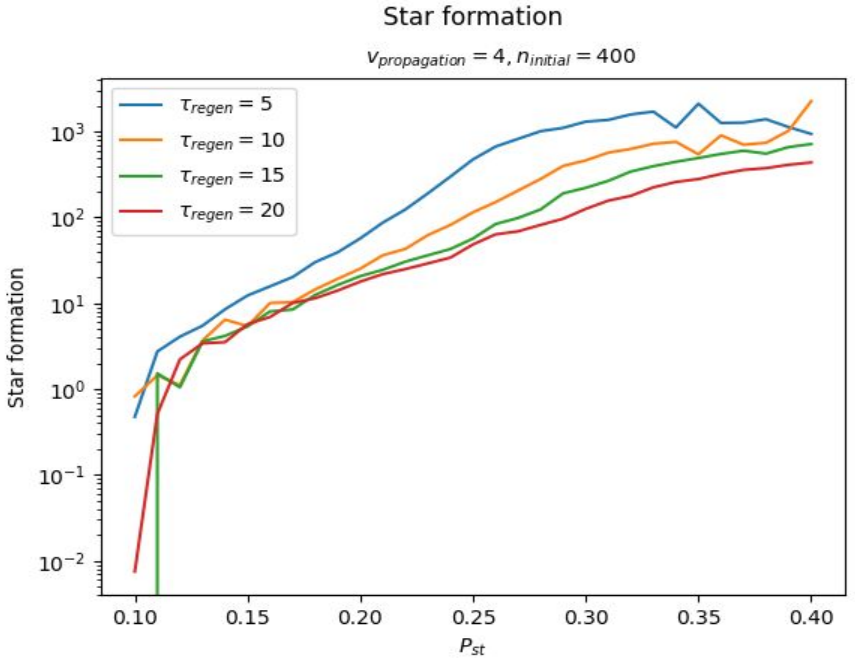
Phase 3: spiral forming
P = 0.3



Propagation phase transition

- Sharp asymptotic behaviour
- Critical probability around 0.11

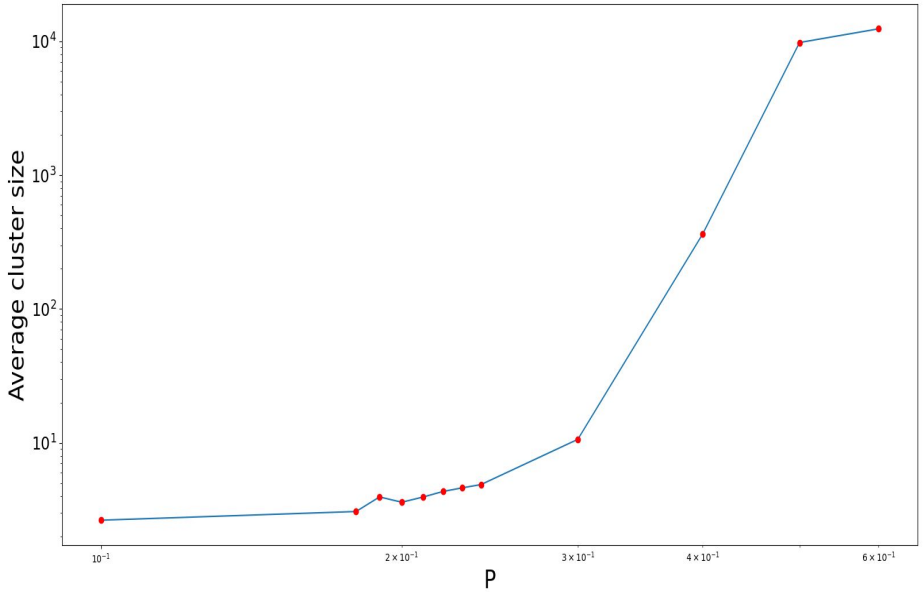




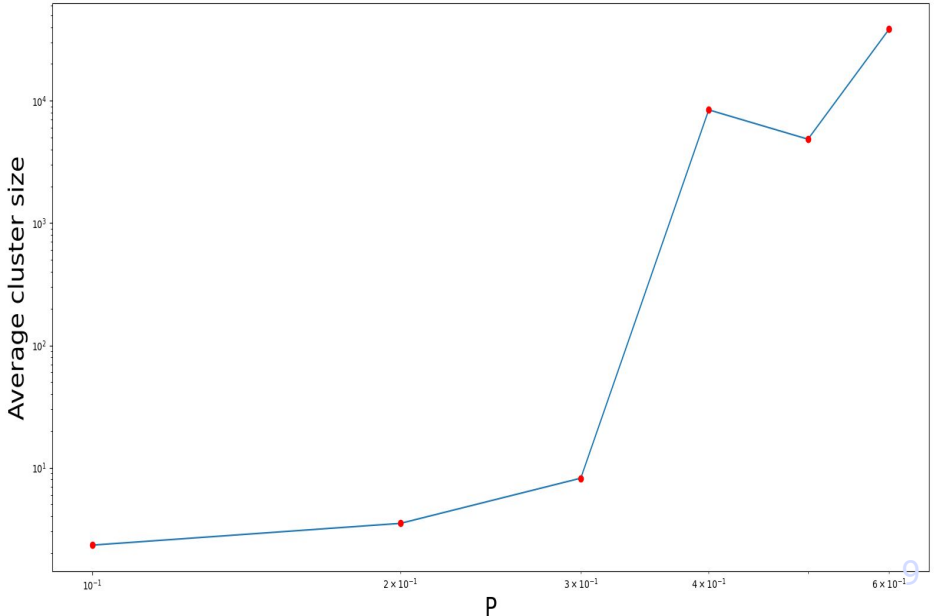
Percolation: average cluster size

Initial stars = 200; Regeneration time = 50

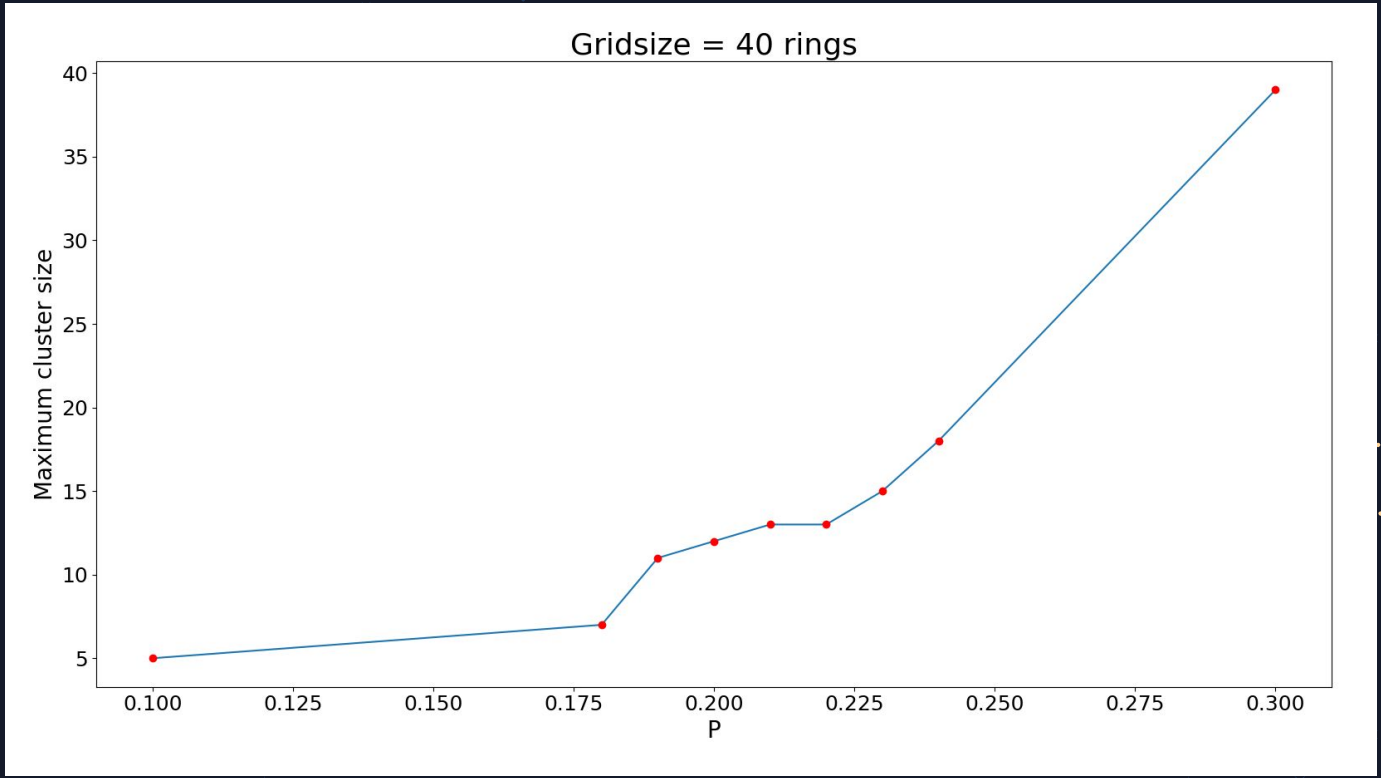
Grid size = 40 rings



Grid size = 80 rings



Percolation at P=0.3



Conclusion

Hypothesis accepted: our model shows the assumption is valid.

Major findings:

- Three phases: no propagation, propagation and spiralling
- All 64 simulations show the critical propagation probability falls within the range between p=0.1-0.2
- Critical probability for percolation is p=0.3.

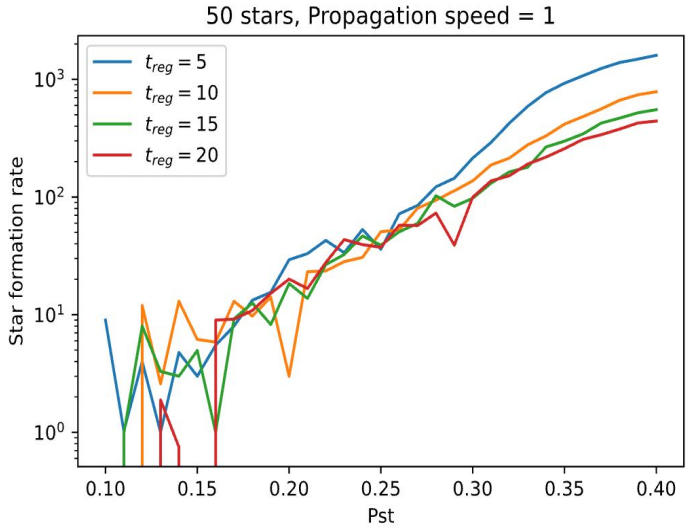
Limitations:

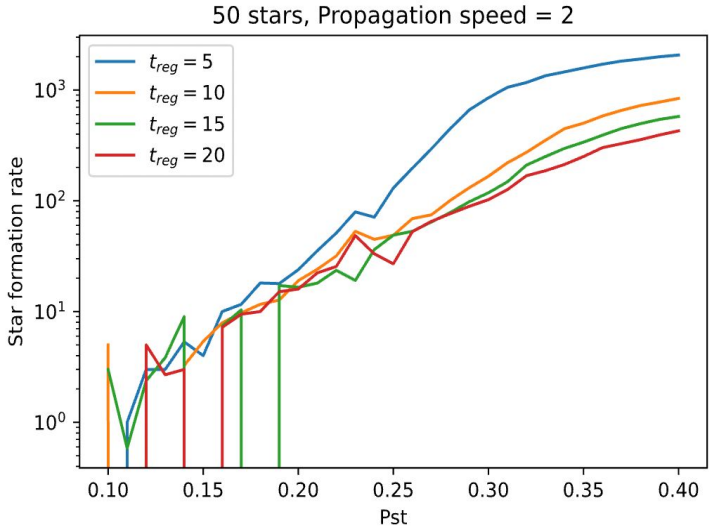
- the model can be used for many spiral galaxies but not all, some spiral galaxies still need to use dynamic theories to explain and need to collect observational data to confirm the findings.
- Computational time, no code available
- Limited research papers available

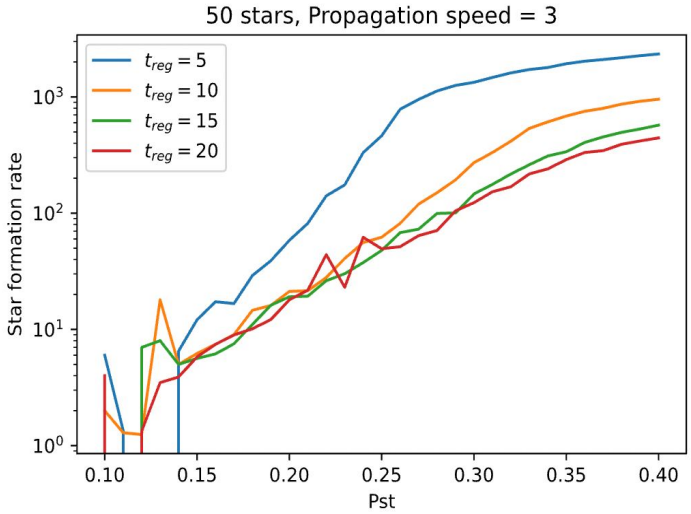
Appendix

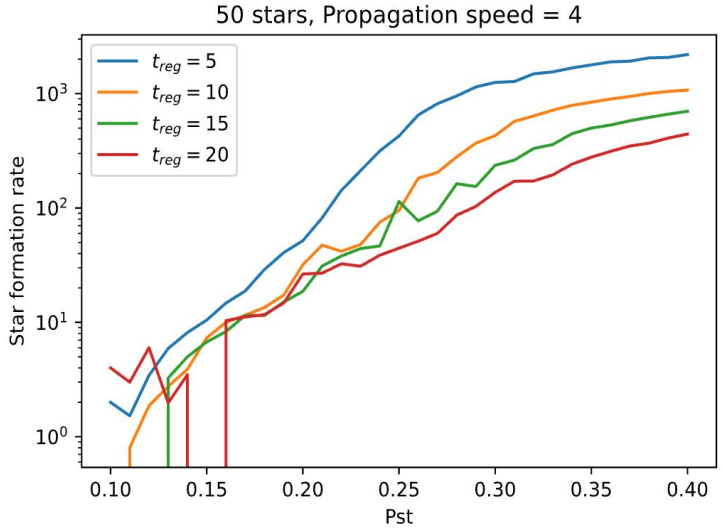
Slides 13-16:

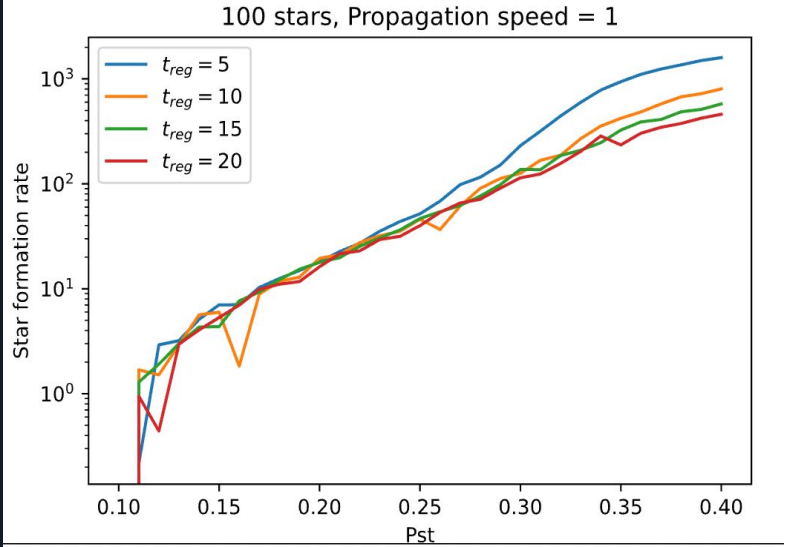
- Experiment 2, plots of all 64 simulations
- initial stars = 50, 100, 200, 400
- propagating speed= 1, 2, 3, 4
- regeneration time= 5, 10, 15, 20

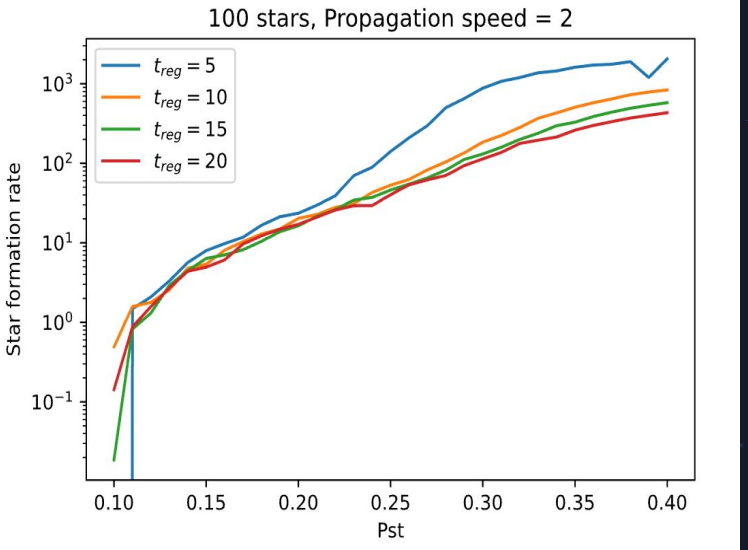

50 stars, Propagation speed = 1
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$
Star formation rate
10^0
10^1
10^2
10^3
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Pst


50 stars, Propagation speed = 2
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$
Star formation rate
10^0
10^1
10^2
10^3
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Pst


50 stars, Propagation speed = 3
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$
Star formation rate
10^0
10^1
10^2
10^3
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Pst


50 stars, Propagation speed = 4
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$
Star formation rate
10^0
10^1
10^2
10^3
0.10
0.15
0.20
0.25
0.30
0.35
0.40
Pst


100 stars, Propagation speed = 1
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$
Star formation rate
Pst


100 stars, Propagation speed = 2
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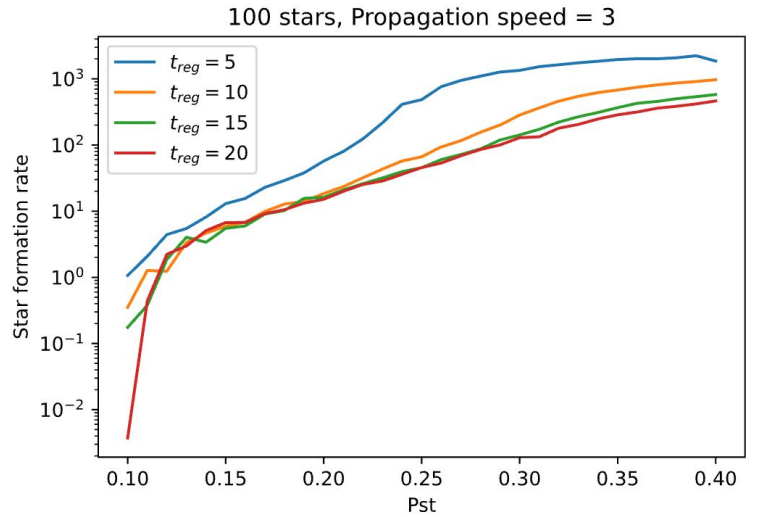
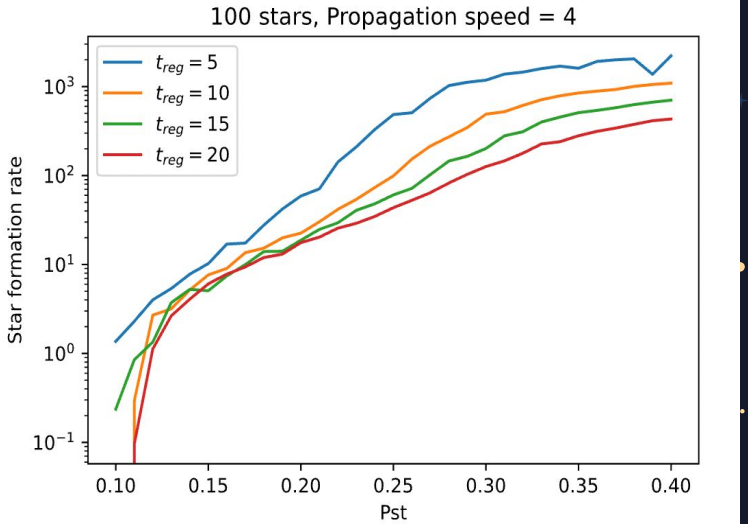
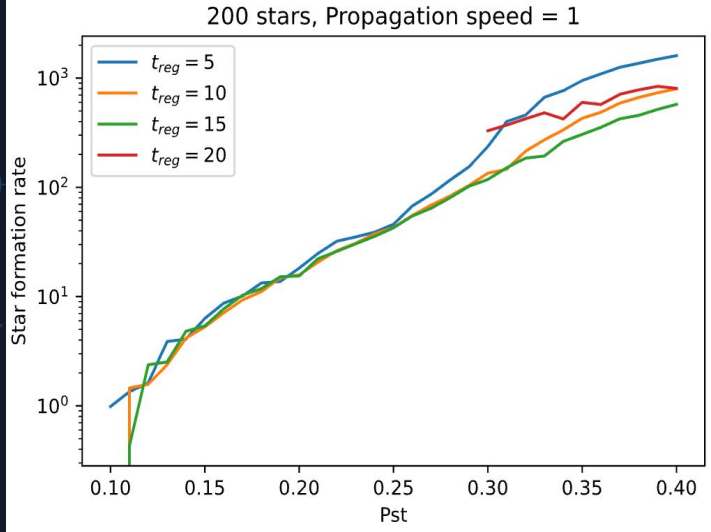
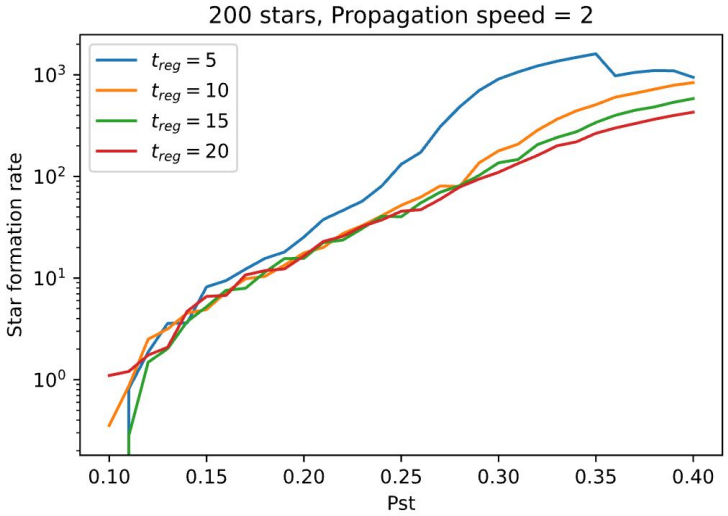
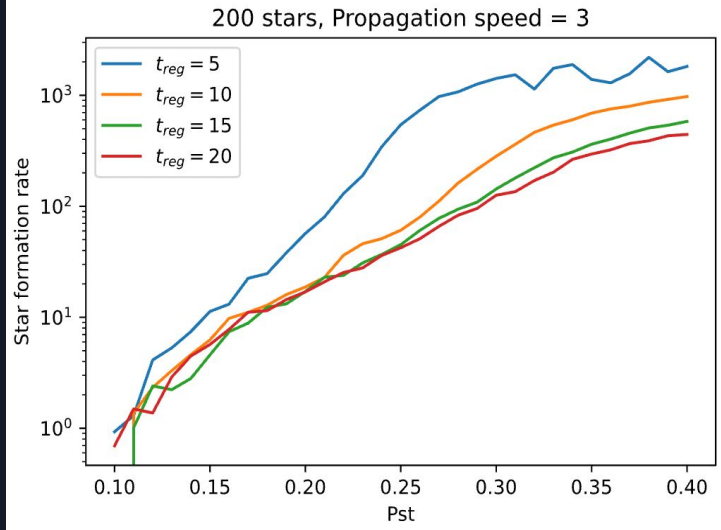
$t_{reg} = 20$
Star formation rate
Pst

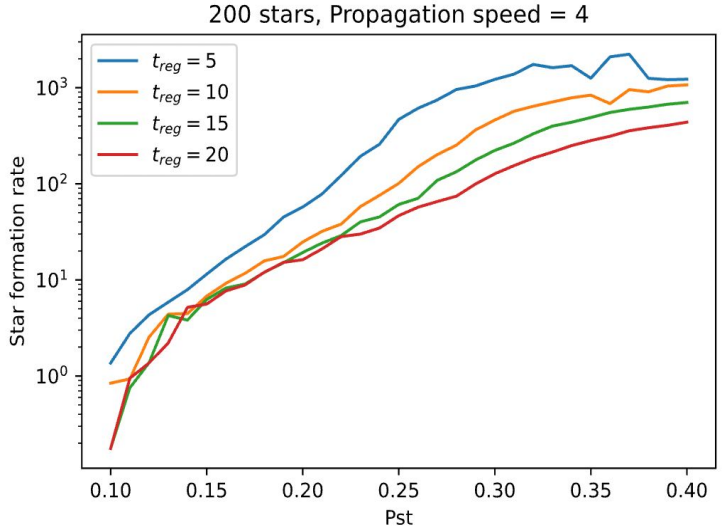

100 stars, Propagation speed = 3
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$
Star formation rate
Pst

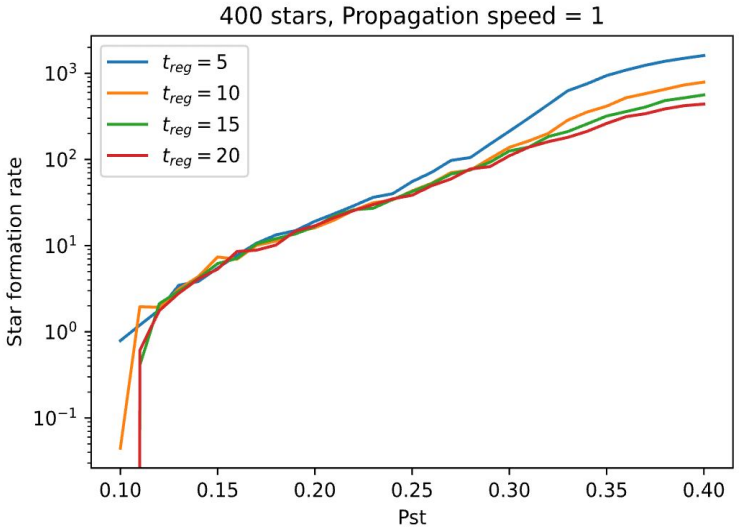

100 stars, Propagation speed = 4
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$
Star formation rate
Pst


200 stars, Propagation speed = 1
Star formation rate
Pst
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$


200 stars, Propagation speed = 2
Star formation rate
Pst
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$


200 stars, Propagation speed = 3
Star formation rate
Pst
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$


200 stars, Propagation speed = 4
Star formation rate
Pst
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$


400 stars, Propagation speed = 1
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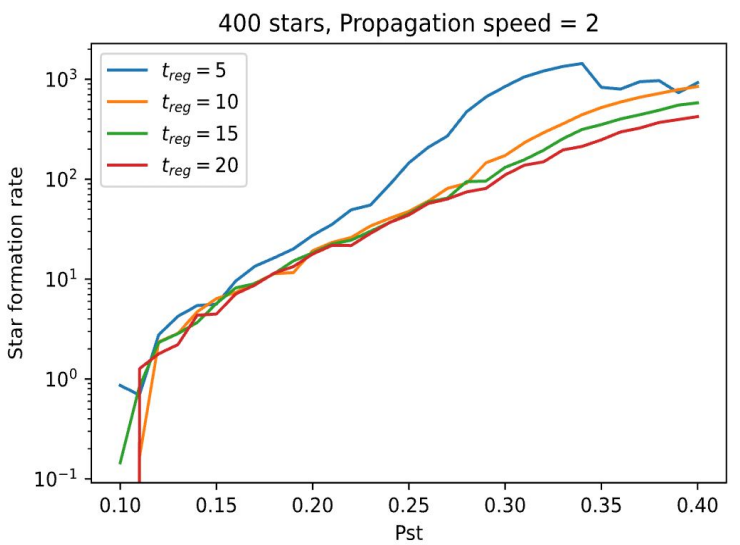
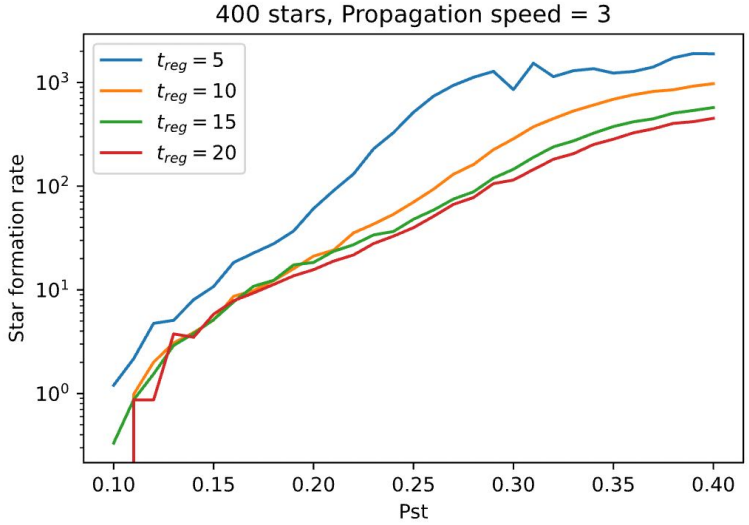
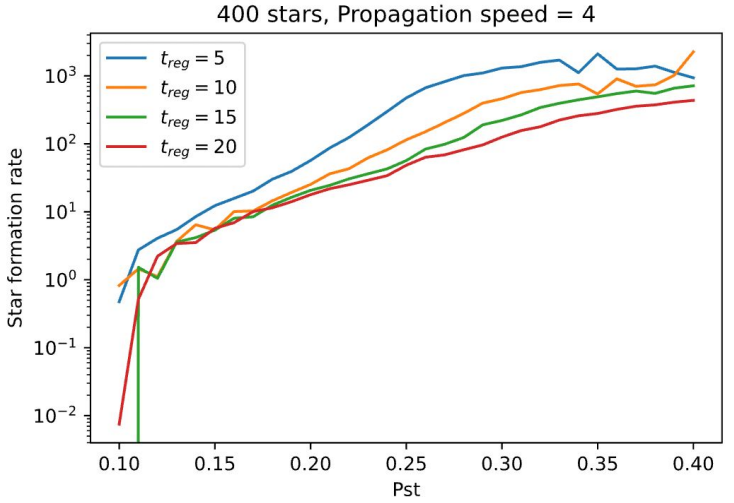
$t_{reg} = 15$
$t_{reg} = 20$
Star formation rate
Pst


400 stars, Propagation speed = 2
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$
Star formation rate
Pst


400 stars, Propagation speed = 3
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$
Star formation rate
Pst


400 stars, Propagation speed = 4
$t_{reg} = 5$
$t_{reg} = 10$
$t_{reg} = 15$
$t_{reg} = 20$
Star formation rate
Pst