

Setting up a stable disc galaxy in Phantom of RAMSES

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Motivation

- Milgromian dynamics (MOND) successfully reproduces rotation curves of galaxies,
- Simulations need stable initial conditions unless the full formation history (from the Big Bang...) is computed,
- Phantom of RAMSES provides a useful platform for Milgromian computations.

Motivation

- Galaxy consists of baryonic matter only,
- Potential governed by Milgromian gravity,
- Setup in virial equilibrium not as straight-forward as in Newtonian gravity + DM — requires solving modified Poisson equation.

Backbone

- Given galaxy parameters: mass, size, bulge, Q ...
- Assume bulge in purely Newtonian regime,
- Create static dummy disc, solve Newtonian Poisson equation,
- Compute Milgromian potential by solving the QUMOND Poisson equation:

$$\nabla^2 \Phi(x) = 4\pi G \rho_b(x) + \nabla \cdot [\nu (|\nabla \phi|/a_0) \nabla \phi(x)]$$

or rewritten as

$$\nabla^2 \Phi(x) = 4\pi G (\rho_b(x) + \rho_{ph}(x))$$

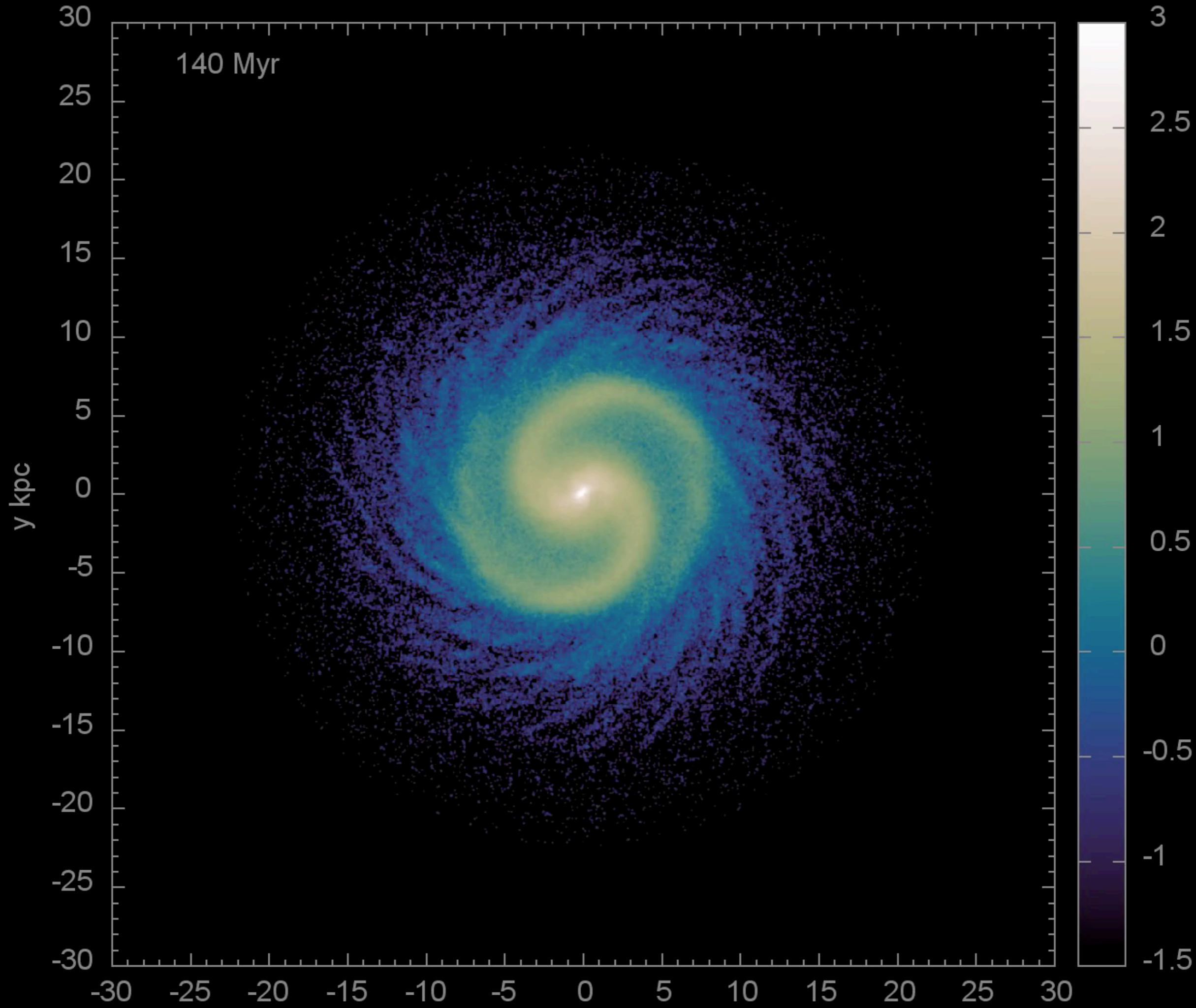
- Compute the velocities, populate the run-ready disc.

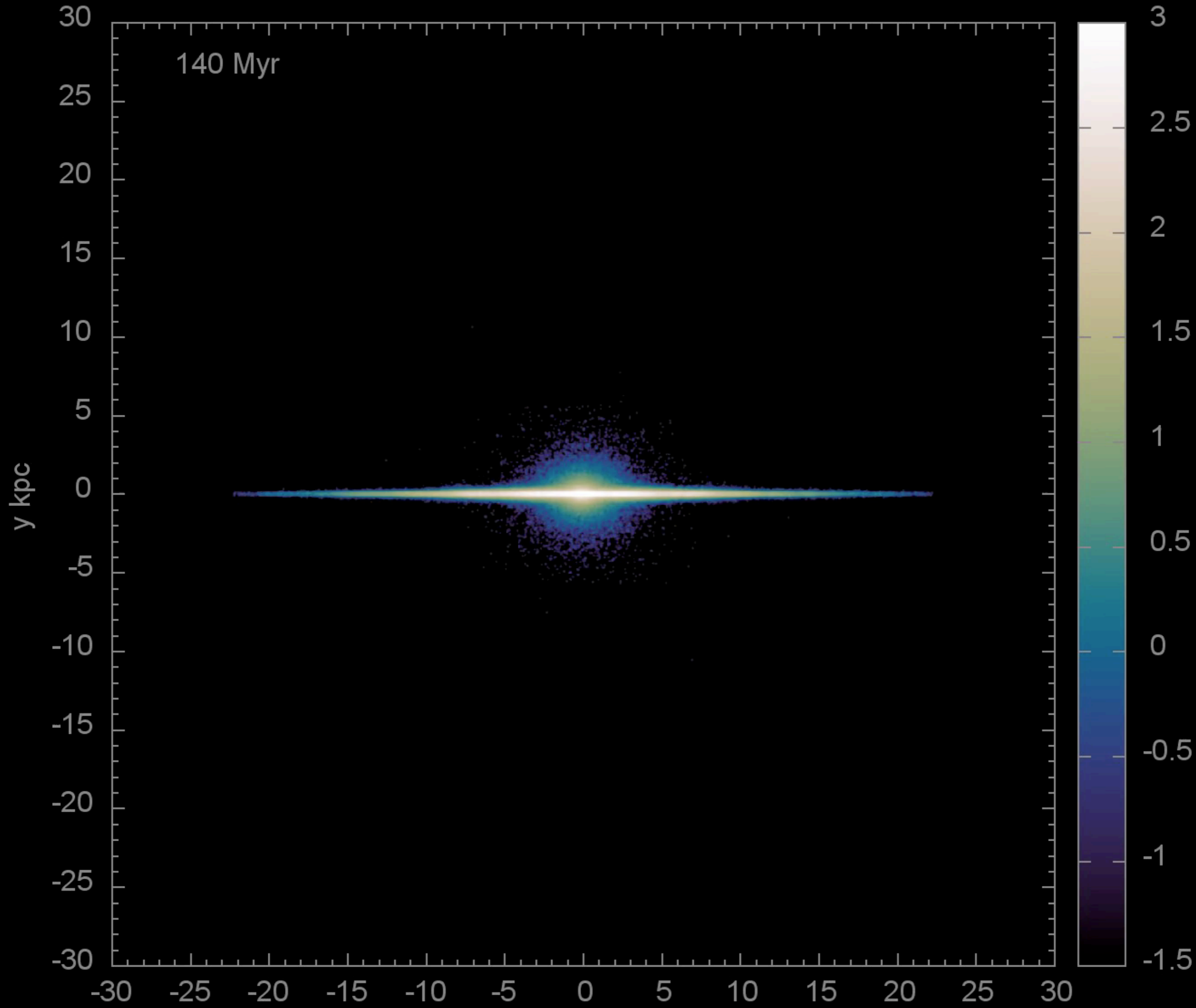
Requirements

- Phantom of RAMSES (PoR) installation
- pNbody (Python lib for N-body computations)
- NEMO (toolbox for stellar dynamics, simulations etc.)
- mkgalaxy script by Lüghausen (2015)

Example

- Mass: $8 \times 10^{10} M_{\text{sun}}$,
- Bulge: 0.1 disc mass,
- Disc scale radius: 2 kpc,
- $Q=1.5$ (marginally unstable),
- Stars only (no gas),
- 1 Million particles used (i.e. $8 \times 10^4 M_{\text{sun}}$ each),
- Setup takes 2-3 hours, simulation several days.

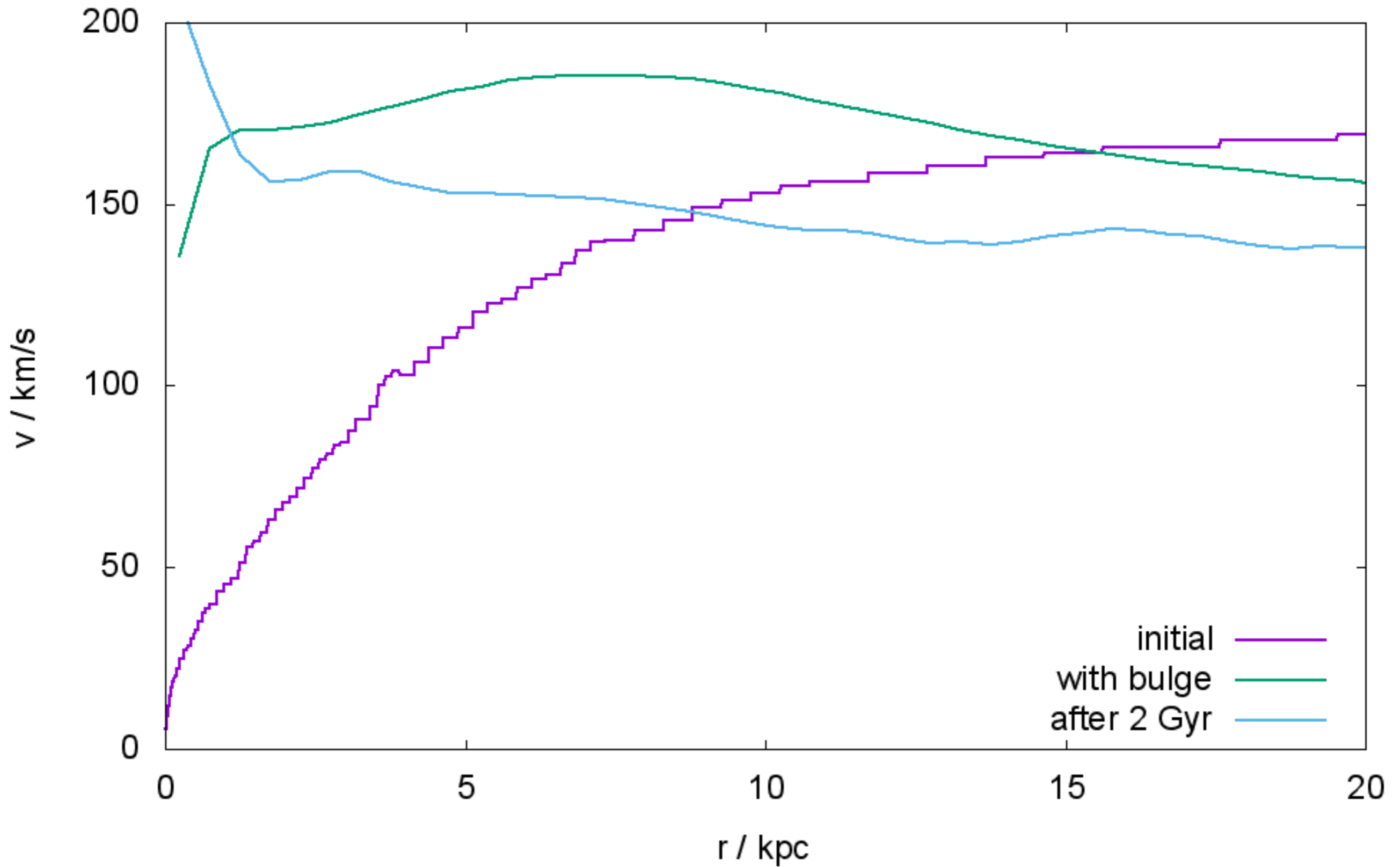




Example

- Disc spreads only slightly after launch,
- Marginal instability causes spiral arms,
- Galaxy heats up dynamically after a few revolutions,
- Transient warps occur,
- Settled disc shows central bar, but only weak spiral arms, no warps.

Rotation curve



Gas content

- RAMSES / PoR is capable of including gas.
- However, this is done by editing the code rather than by IC files.
- Patch on subroutine CONDINIT for custom IC files next target.



Gas simulations are currently under development - stay tuned!

Summary

- Stable disc galaxies can be set up via helper programs,
- Pure stellar discs can be set up readily,
- Discs with gas need editing the RAMSES code,
- Disc is stable after a brief settling period,
- Rotation curve nicely reproduced.

Outlook

- Calculations with gas,
- Provide a more convenient way for gas inclusion,
- Simulation of interacting galaxies, e.g. the M81 group,

The best is yet to come...