A Hybrid N-body code
including Algorithmic Regularization and Post-Newtonian Terms

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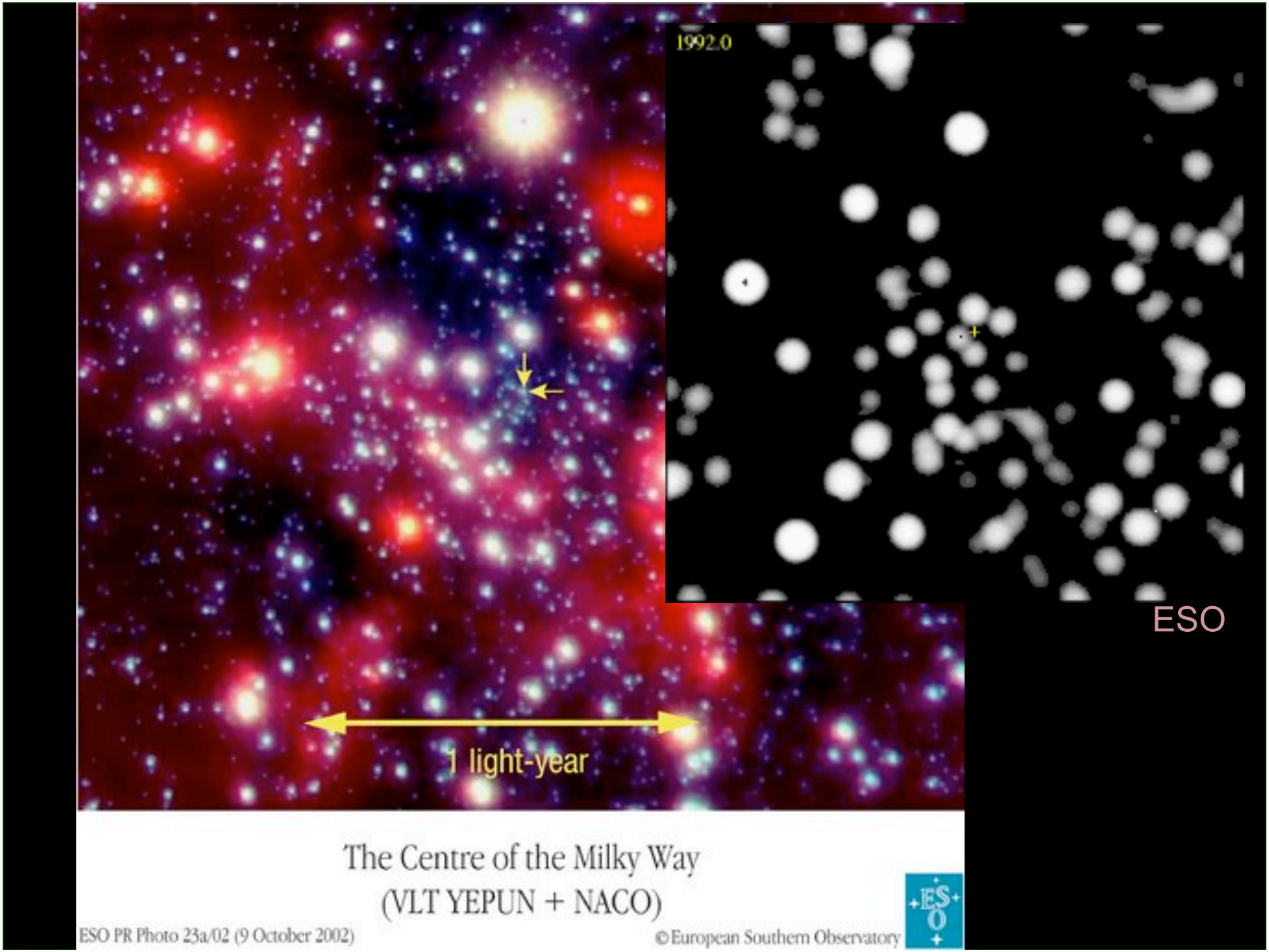
Outline

- Introduction
- φGRAPECH
  - implementation
  - performance
- Evolution of Stars in the Galactic Centre

  ==> “see” talk by Alessia tomorrow

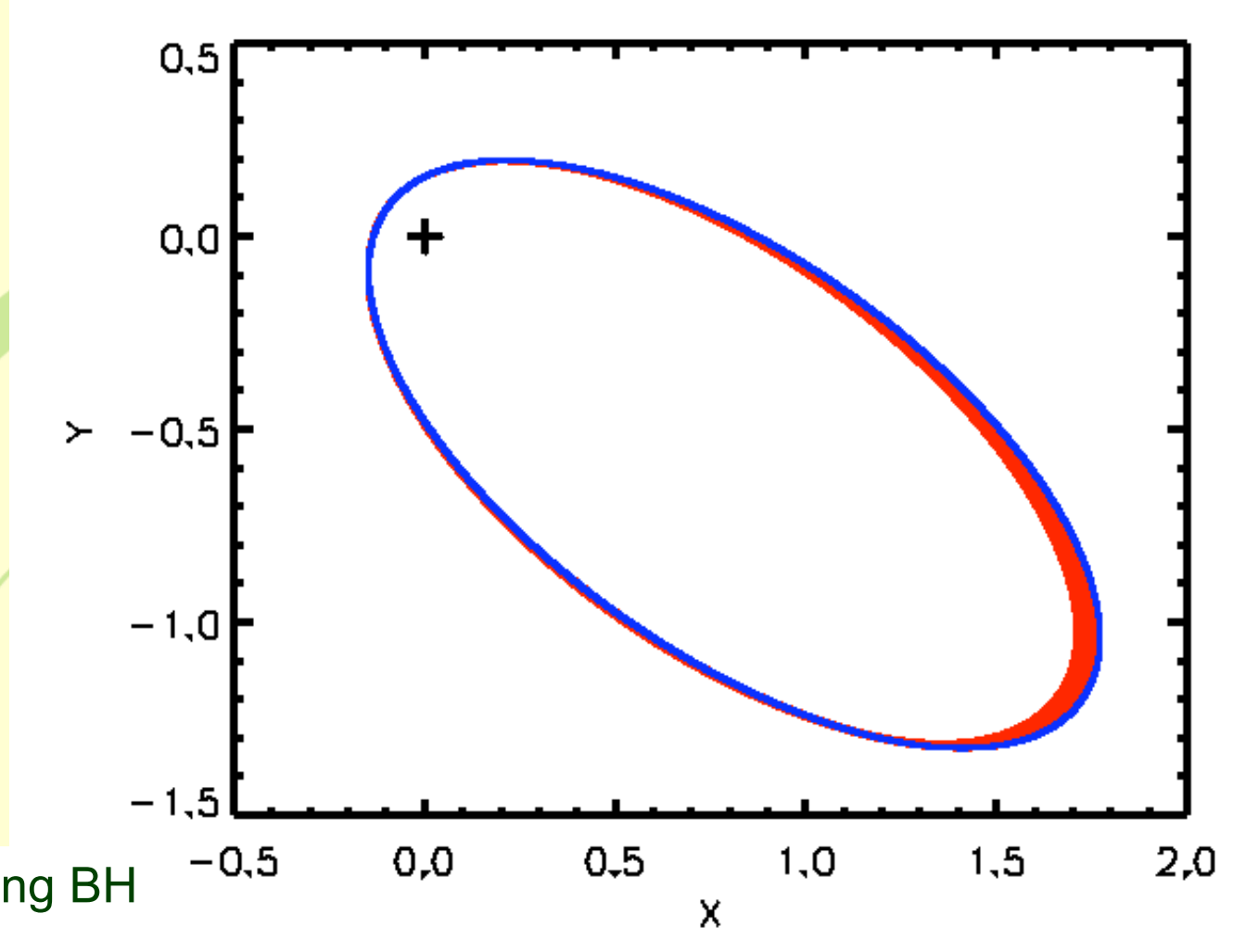


The Centre of the Milky Way
(VLT YEPUN + NACO)

ESO PR Photo 23a/02 (9 October 2002)

N-body algorithms

- approximate methods
  - e.g. TREE codes, Particle-Mesh codes
  - approximate forces of distant particles
  - scale with ~N
- direct N-body codes
  - no approximation used
  - scale with ~N^2
- few-body algorithms
  - e.g. AR-CHAIN
  - extremely accurate integrators
  - computationally expensive



example: star orbiting BH

- mass ratio $\sim 10^{-6}$
- ~ 5000 orbits
- direct N-body vs. AR-CHAIN

φGRAPECH

Harfst, Gualandris, Merritt, Mikkola (2008)
astroph/0803.2310

- New hybrid N-body + chain code combining
  - Nbody: 4th-order Hermite predictor-corrector scheme with hierarchical time-steps and GRAPE support (φGRAPE)

    Harfst, Gualandris, Merritt,
    Portegies Zwart, Berczik, Spurzem (2007)
  - Chain: algorithmic regularization with Post-Newtonian corrections up to 2.5 order (AR-CHAIN)

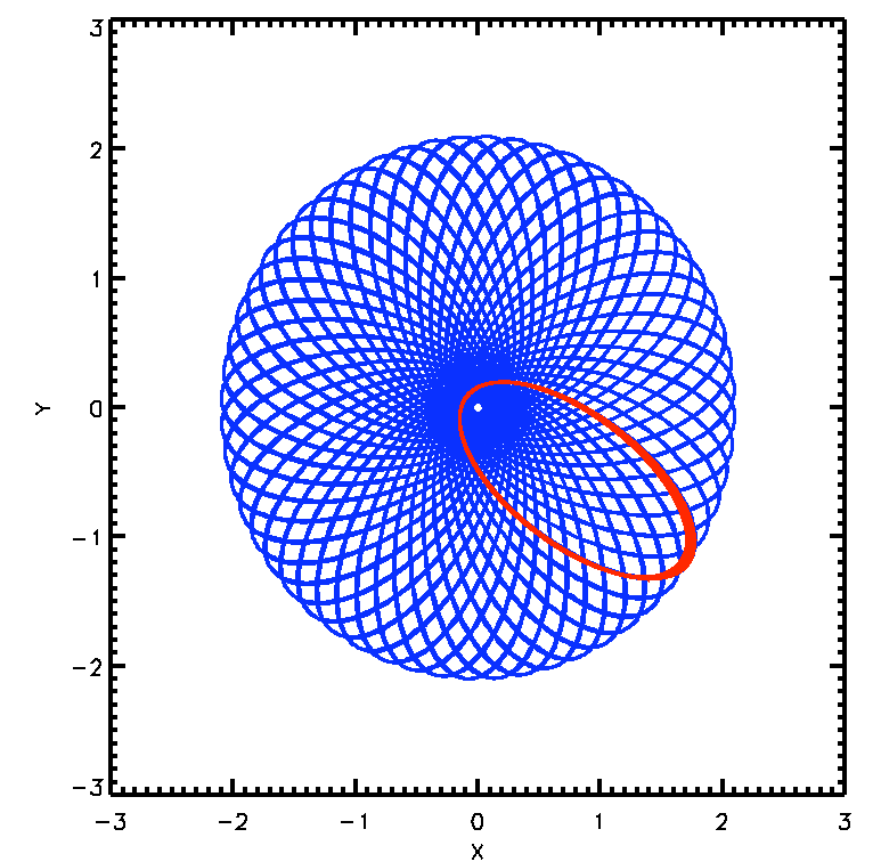
    Mikkola & Merritt (2007)

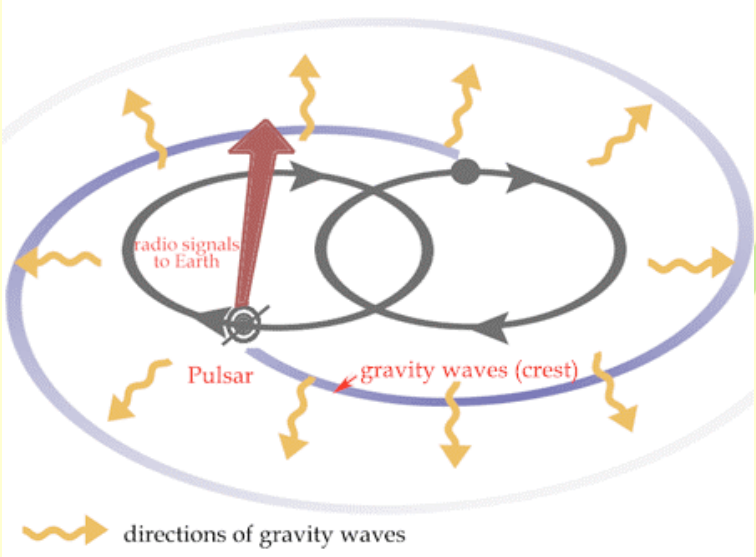
Post-Newtonian Terms

$$\mathbf{a} = \mathbf{a}_0 + c^{-2}\mathbf{a}_2 + c^{-4}\mathbf{a}_4 + c^{-5}\mathbf{a}_5$$

1PN 2PN 2.5PN

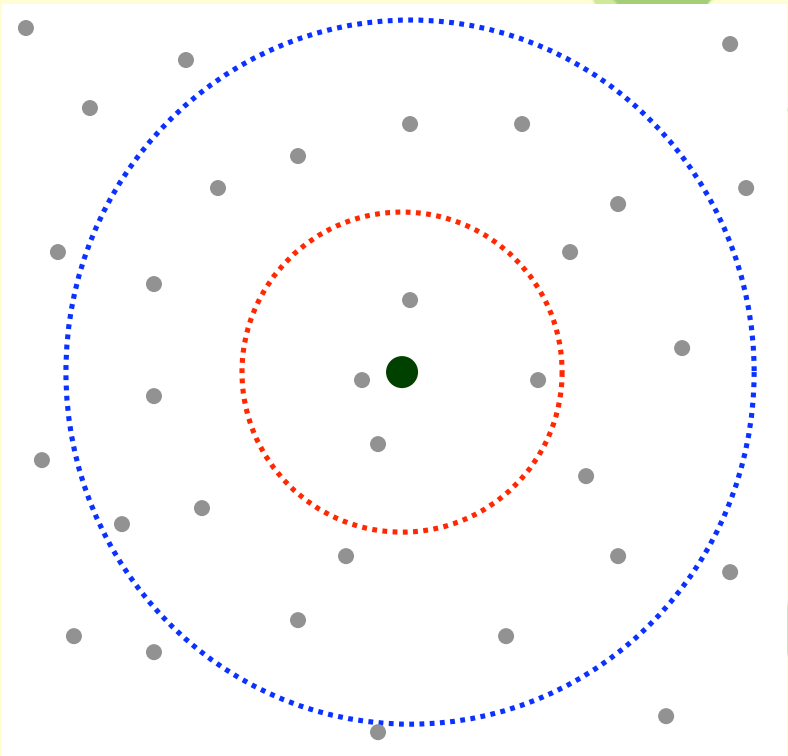
Periastron shift Grav. Rad.





φGRAPECH

- Particles are divided in:
  - CHAIN: $d_{BH} \leq r_{crit}$
  - NBODY
    - perturbers
    - non-perturbers



- Parameters:
  - r_{crit} max distance from the BH to enter the chain
  - $r_{perturb}$ distance for perturber particles

Implementation

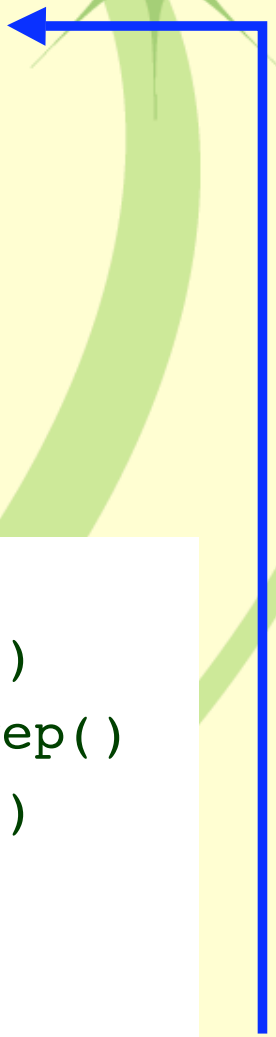
phiGRAPE

AR-CHAIN

```
get_timestep()
set_activep()
if (chain) then
   update_chain()
else
   chain = check_chain()
   if (chain) then
       load_chain()
```

```
if (chain) then
   evolve_chain()
   resolve_chain()
   predict_activep()
   calc_force_activep()
   correct_activep()
   update_grape()
```

```
else
   predict_activep()
   calc_force_activep()
   correct_activep()
   update_grape()
```



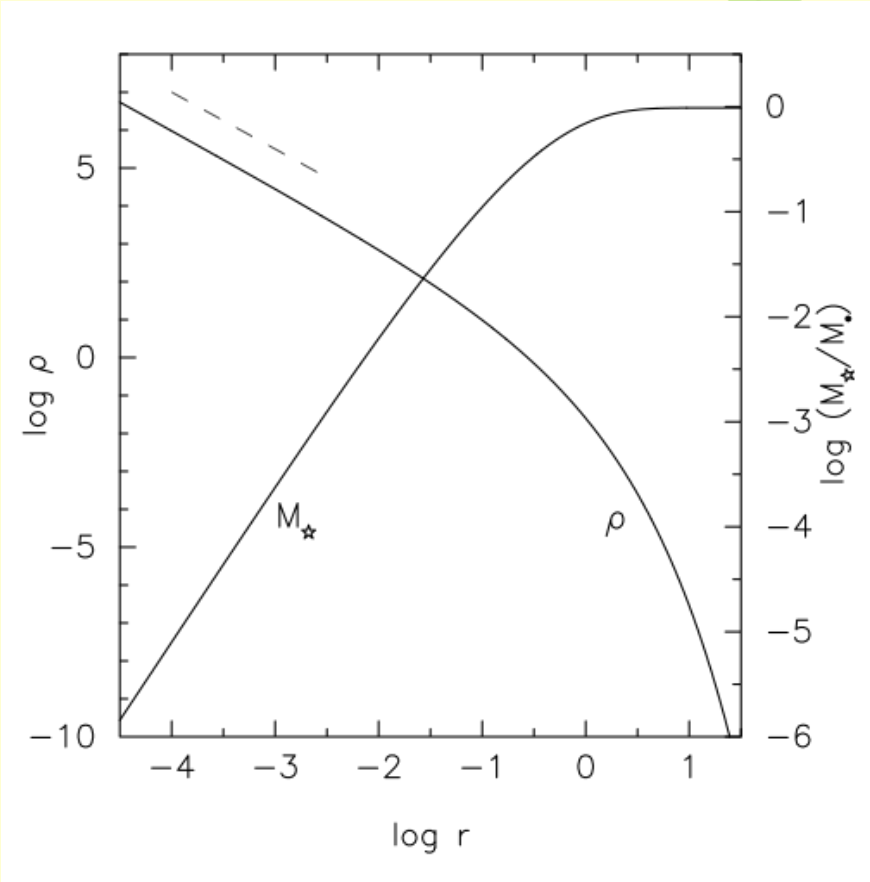
performance tests

Model of the MW star cluster

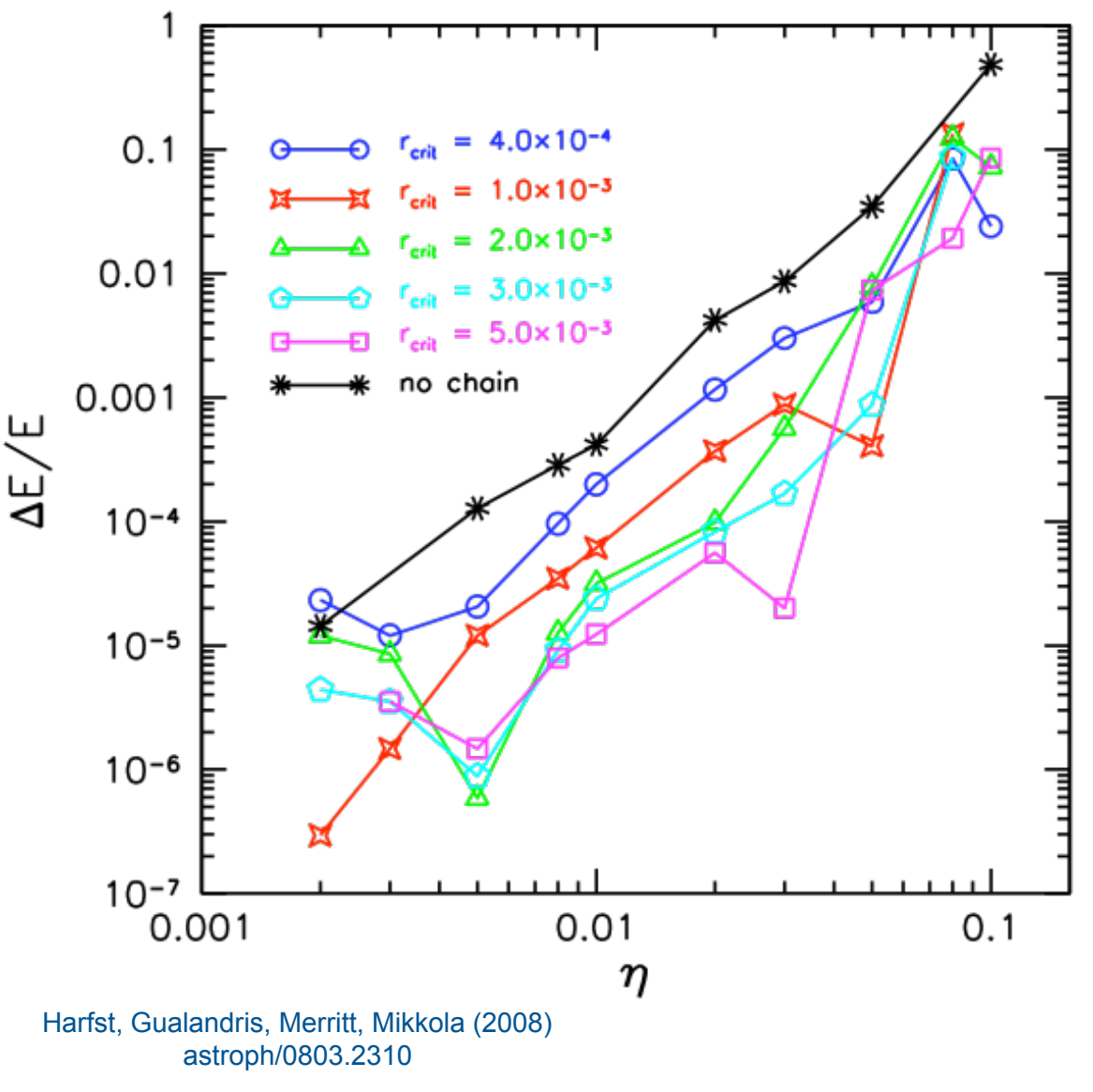
$$\rho(r) = \rho_0 \left(\frac{r}{R_e}\right)^{-3/2} \exp\left[-b\,(r/R_e)^{1/n}\right]$$

$M_{cl} = M_{BH} \quad m = M_{BH}/N$

$M_{BH}=3\times10^6\,M_\odot \quad R_e=1$ pc



energy conservation

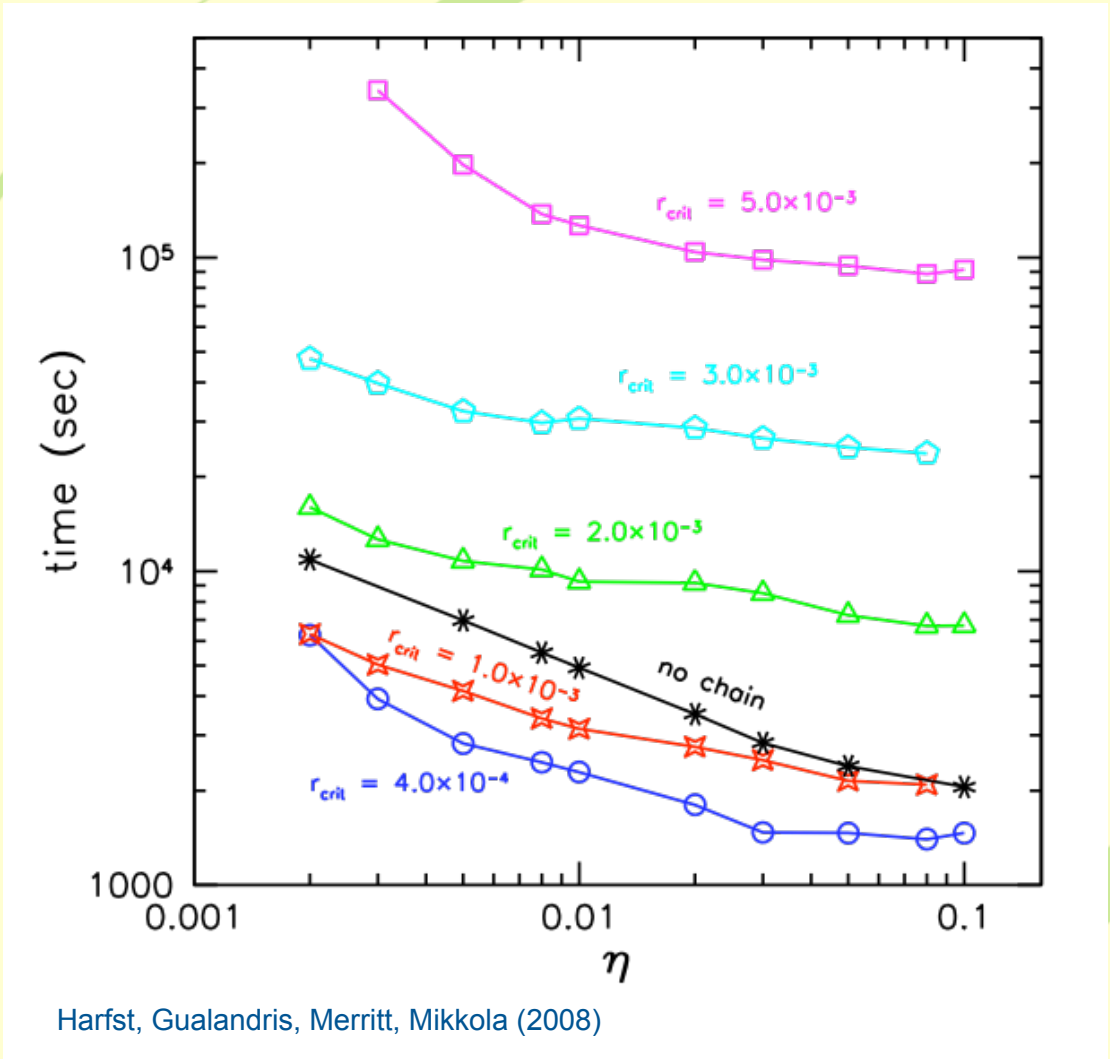


$N = 10^4$

$T \sim 10^4$ yr

Harfst, Gualandris, Merritt, Mikkola (2008)
astroph/0803.2310

wall-clock time



Harfst, Gualandris, Merritt, Mikkola (2008)

$N = 10^4$

$T \sim 10^4$ yr

φGRAPECH can be both more accurate and faster than φGRAPE