GRAPE and Project Milkyway

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Talk overview

- GRAPE Project
- Science with GRAPEs
- Next Generation GRAPE — the GRAPE-DR
- Project Milkyway

GRAPE project

GOAL:

Design and build specialized hardware for simulation of stellar systems.

Rational:

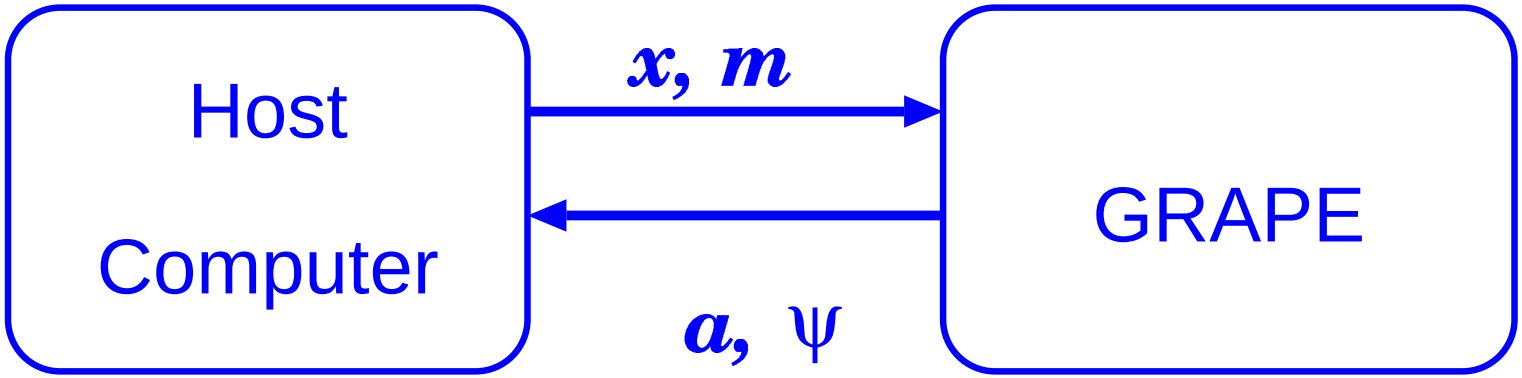
You can do larger simulations (better resolution) for same amount of money.

GRAPE-6	**(2002, 64 TF)**	**4M$**
ASCI White	**(2001, 12 TF)**	**200M$**
ASCI Q	**(2002, 30 TF)**	**200M$**
Earth Simulator	**(2002, 40 TF)**	**300M$**

Basic idea of GRAPE

Special-purpose hardware for force calculation
General-purpose host for all other calculation

$$\frac{d^2\mathbf{x}_i}{dt^2} = \sum_{j \neq i} -Gm_j \frac{\mathbf{x}_i - \mathbf{x}_j}{|\mathbf{x}_i - \mathbf{x}_j|^3}$$



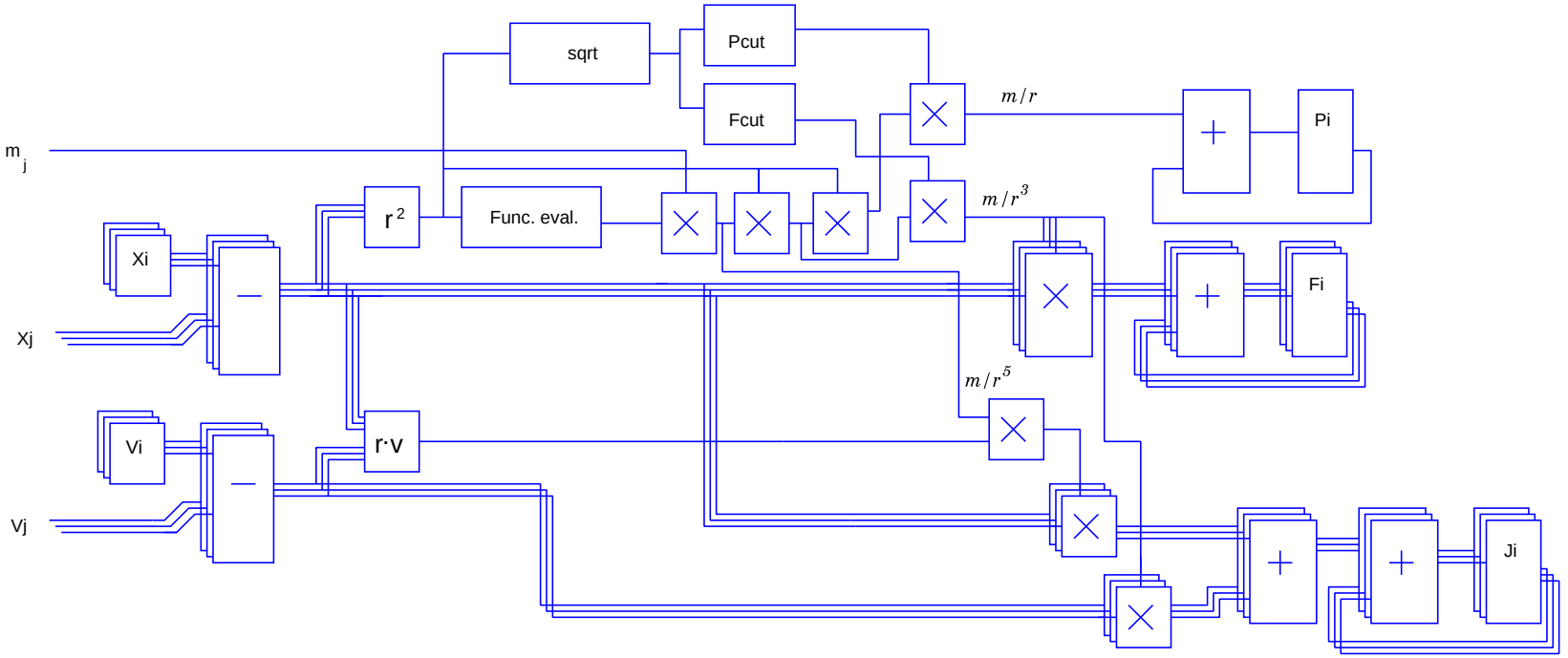
Time integration, IO, etc

Force calculation

Flexibility

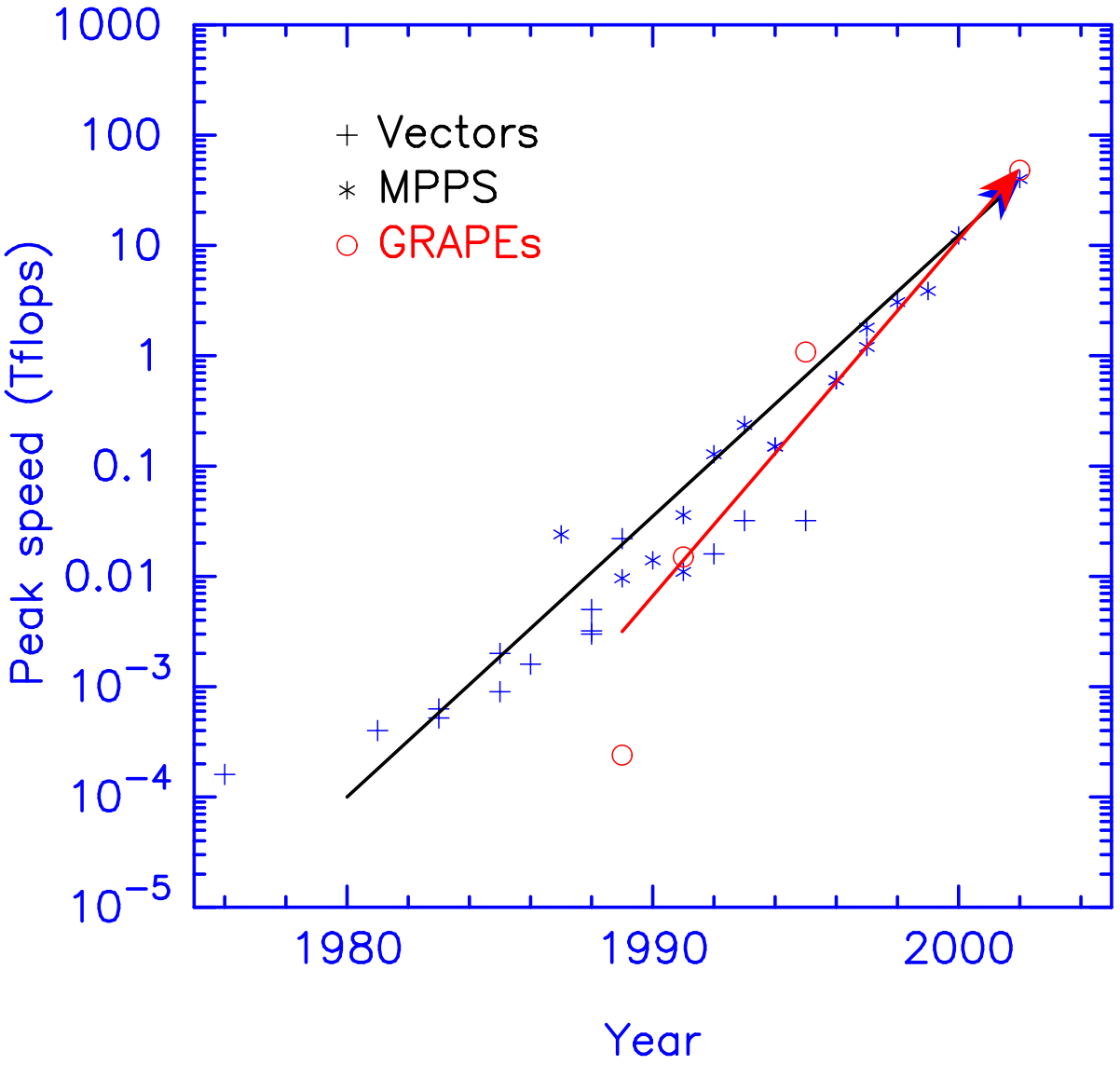
High performance

GRAPE-6 Processor pipeline

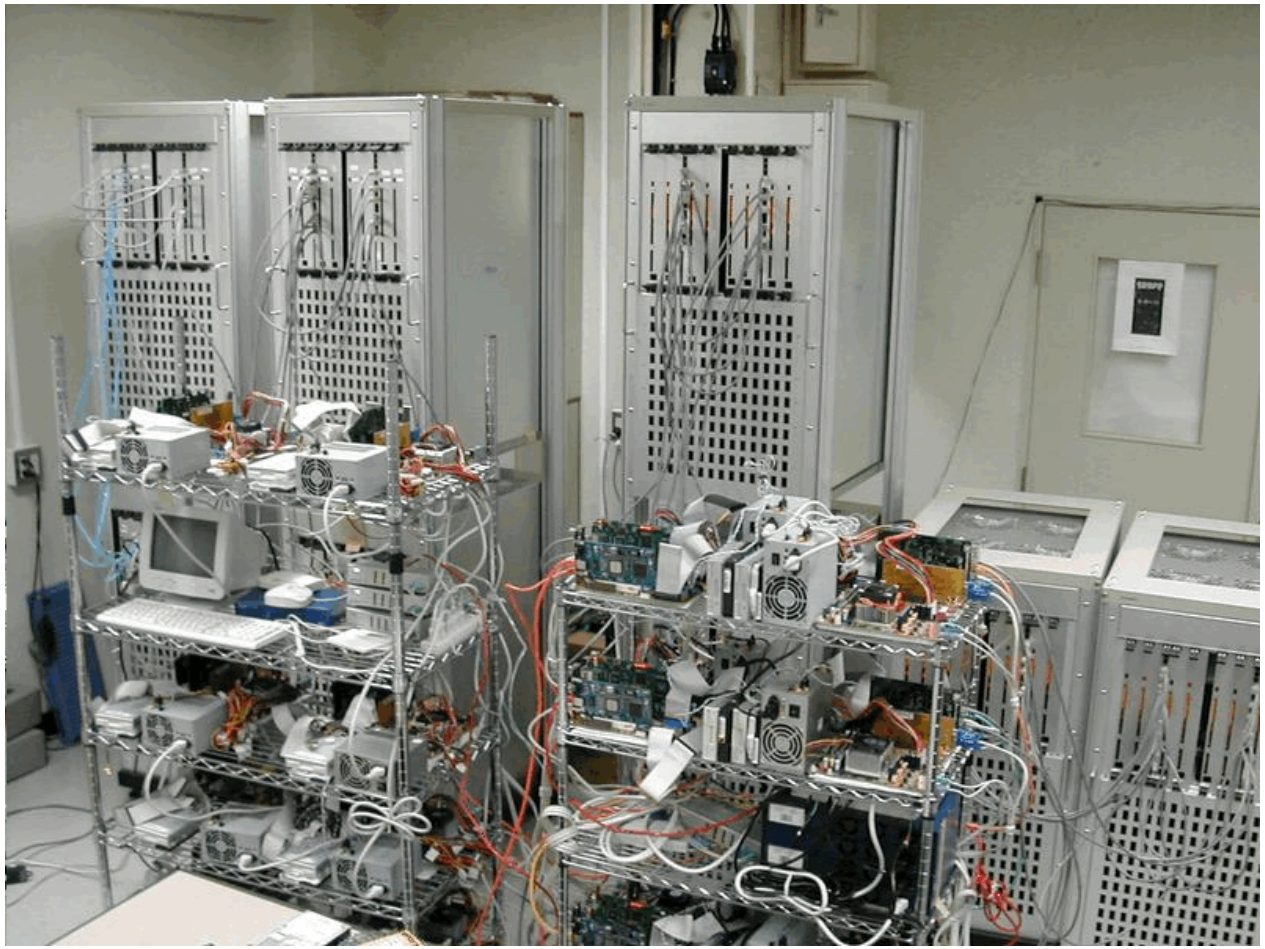


Calculates gravitational force, its first time derivative and potential.

Evolution of GRAPE systems



GRAPE-6



64 Tflops peak speed

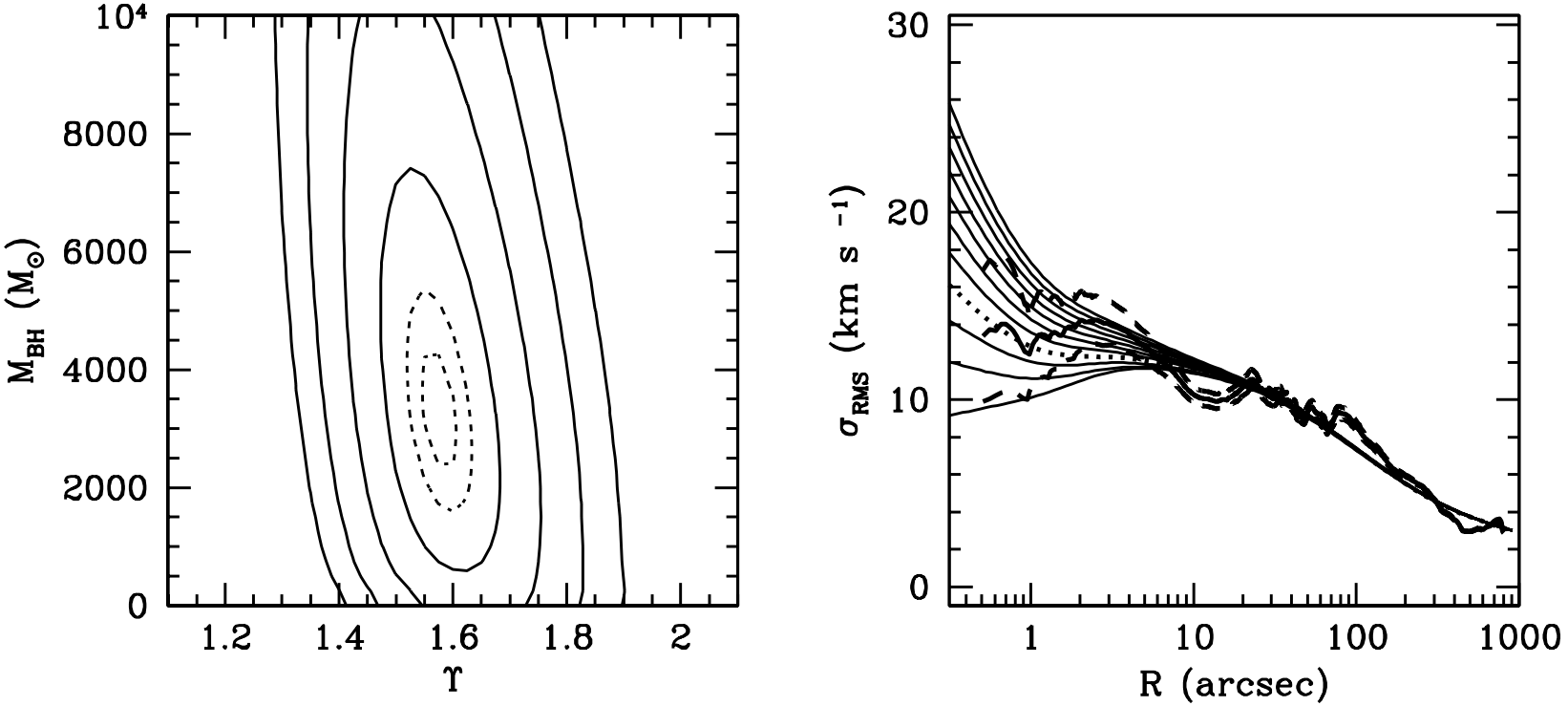
Three Gordon-Bell Prizes (2000, 2001, 2003)

Science with GRAPE

- Solar system/Planetary formation
- Star-forming region/Open clusters
- Globular clusters
- Galactic nuclei
- Galaxy formation
- Clusters of Galaxies/Cosmology

Central Black Hole in Globular Clusters?

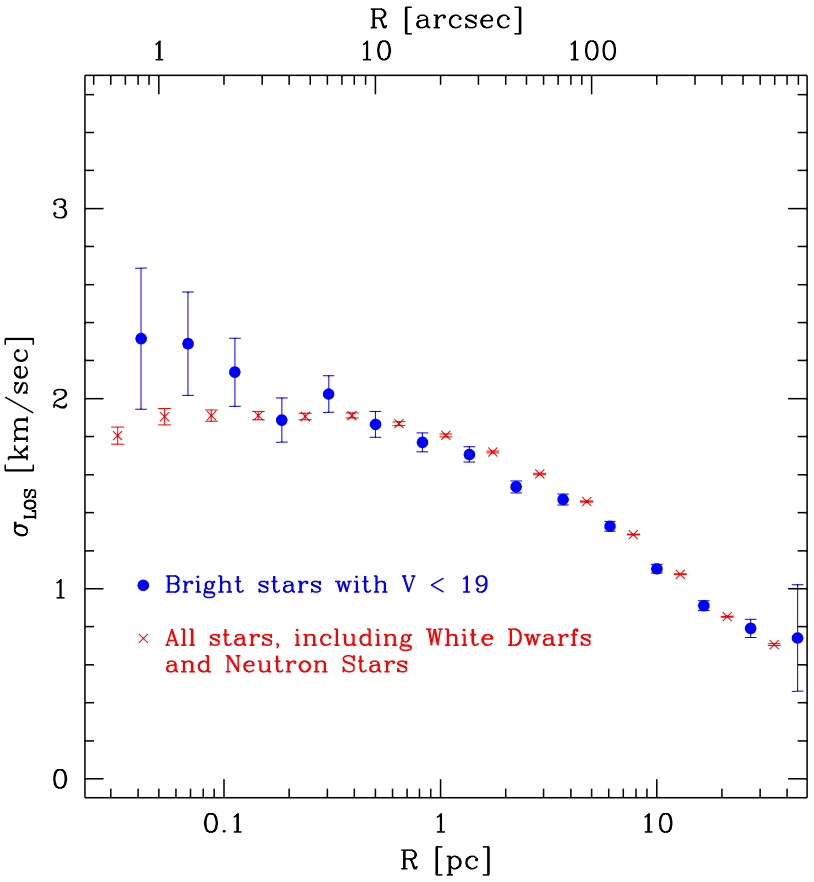
Observation + Interpretation

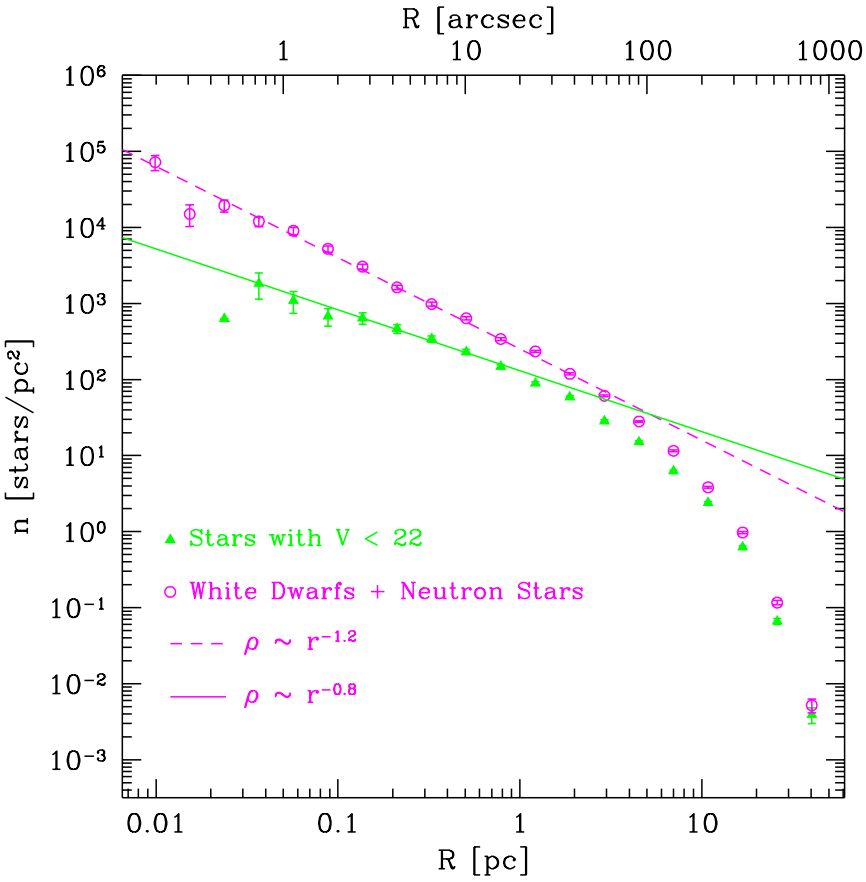


3000 $M_\odot$ black hole? (Gerssen et al 2002)

N-body simulation without BH

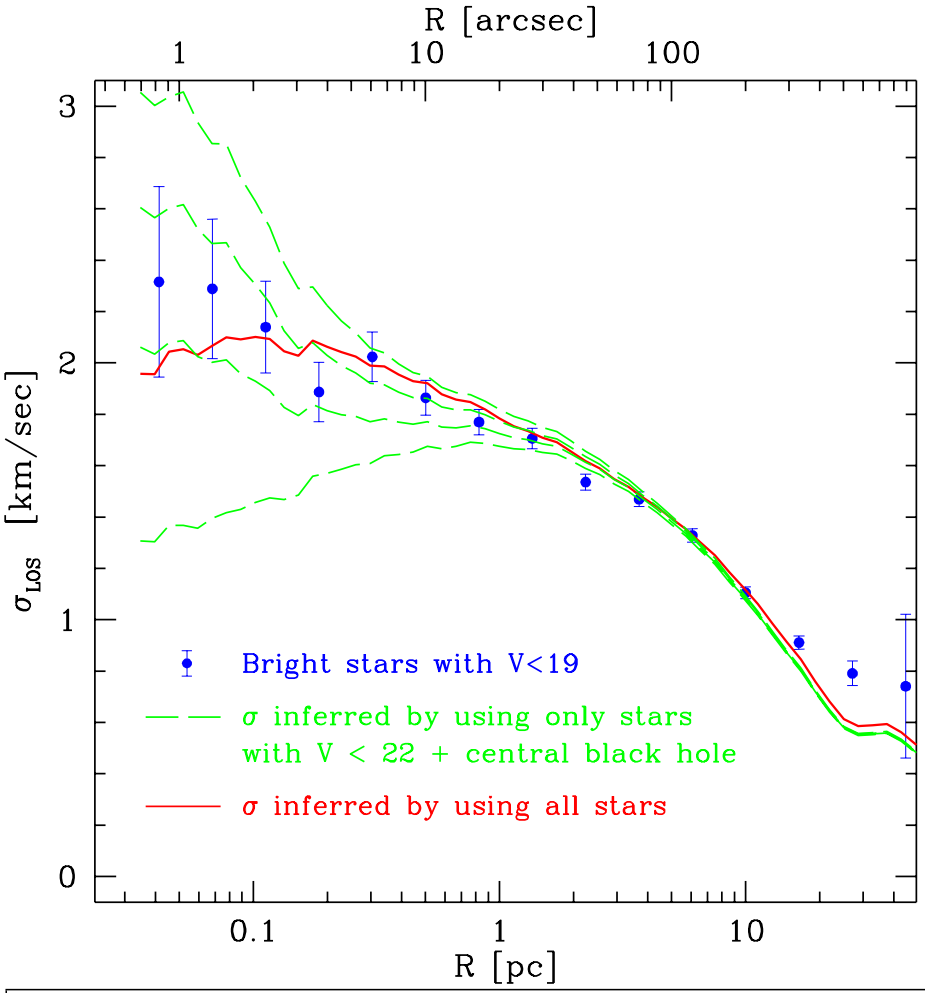
Baumgardt et al., ApJ 2003, 582, L21.





Left: velocity dispersion; Right: Surface density.

We "found" BH, though there wasn't



Inversion of surface number density of bright stars gives too small central velocity dispersion without central BH.

Estimated BH mass = $80M_\odot$. If scaled to M15, $\sim 3 \times 10^3 M_\odot$ (Gerssen *et al.*: $\sim 3 \times 10^3 M_\odot$)

M 15 does not need black hole.

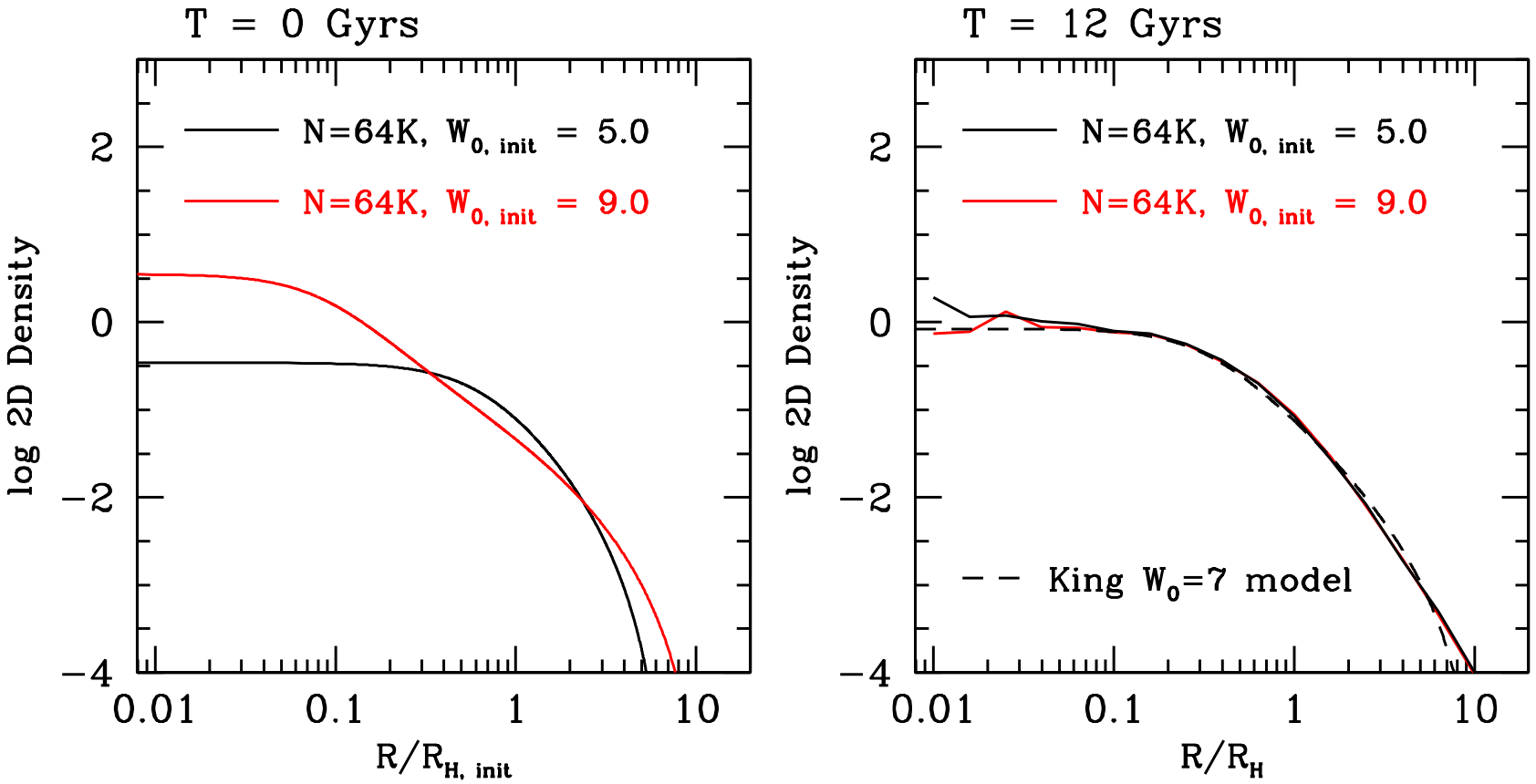
Is there any globular cluster with central BH?

Baumgardt et al. 2004 (ApJL, submitted)

How would it look like?

Evolution globular clusters with central BH for Hubble time.

Profile evolution



Surface brightness profile becomes King7-like. Almost independent of initial profile and BH mass (in the range of 0.1% to 1%)

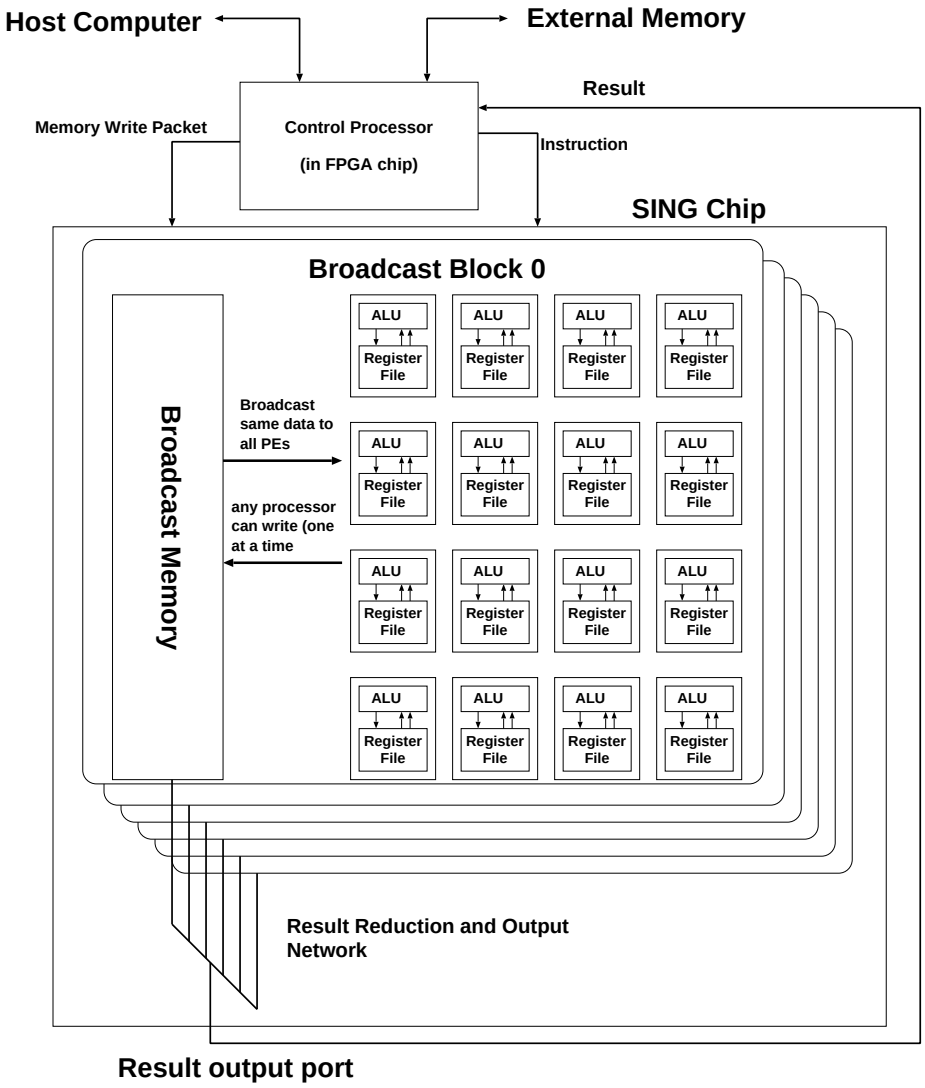
Globular cluster summary

- **Globular clusters with central luminosity cusp do not contain massive central BH. They are really clusters in deep core collapse, with NS and WD dominating the central cusp.**
- **Most likely place to find massive central BH is some of normal-looking clusters with relatively large cores.**

Next-Generation GRAPE — GRAPE-DR

- Budget approved. (1.5M$ $\times$ 5 years)
- Planned peak speed: 2 Pflops
- New architecture — wider application range than previous GRAPEs
- Planned completion year: 2008

GRAPE-DR processor structure



Collection of small processor, each with ALU, register file (local memory)

One chip will integrate (hopefully) 1024 processors
Single processor will run at 700MHz clock (2 operations/cycle).

Peak speed of one chip: 1-2 Tflops (30-60 times faster than GRAPE-6).

Project Milkyway

Wada, Tomisaka (NAOJ), JM, Yoshida (Nagoya) and others

Project goal:
To really give the definite answer to questions like:

- **How the Milkyway Galaxy formed?**
- **What is the origin of the morphological diversity?**

State- of-the-art Nbody+SPH simulations:

- $N \sim 10^5$
- **Mass resolution** $\sim 10^6 M_\odot$

Cannot resolve:
Gas disk, Star forming region

Project requirement

- **Achieve the mass resolution (at least) 10^3 times better than highest value tried so far**

This requires computing power (at least) 10^3 times larger than currently used.

Is this realistically possible?

Computing resource requirement

What is currently done:
Several-month calculation (equivalent) on either

- **Mid-size PC cluster ($\sim$ 100 nodes)**
- **Single GRAPE-5/6 (1 host, 100 $\sim$ 500 Gflops)**

We will need Petaflops$\cdot$ month.

- **GRAPE-DR cluster (256 nodes, 1 Pflops) for Nbody/SPH**
- **Vector-parallel machine (a la Earth Simulator) for grid hydro/radiative transfer**

Summary

- **GRAPE project has successfully developed very high performance computers for astrophysical particle-based simulations.**
- **The next machine, GRAPE-DR, will have wider application range than traditional GRAPEs**
- **Project Milkyway aims at simulating the formation of galaxies with resolution high enough to really resolve and model gas disk and star-forming regions.**