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Dynamical Models of the Globular Clusters M4 and NGC 6397

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Outline

Introduction:

- M4 and NGC 6397
- modelling globular clusters
- surface brightness profiles

What shapes the surface brightness profile?

- core collapse
- binaries
- intermediate-mass black holes
- stellar-mass black holes
- accidents

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Two nearby galactic globular clusters

M4

NGC 6397

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Modelling globular clusters

1. Static (non-evolving) models
   - Example: King's model
     [*something* like a generalized isothermal model of a star]

2. Dynamic (evolutionary) models
   - Example A: *N*-body models
     but globular clusters are/were too big
   - Example B: Monte Carlo models (this talk)
     (i) *Similar level of detail as N-body models*
     (ii) *More assumptions than N-body models, e.g. spherical symmetry.*

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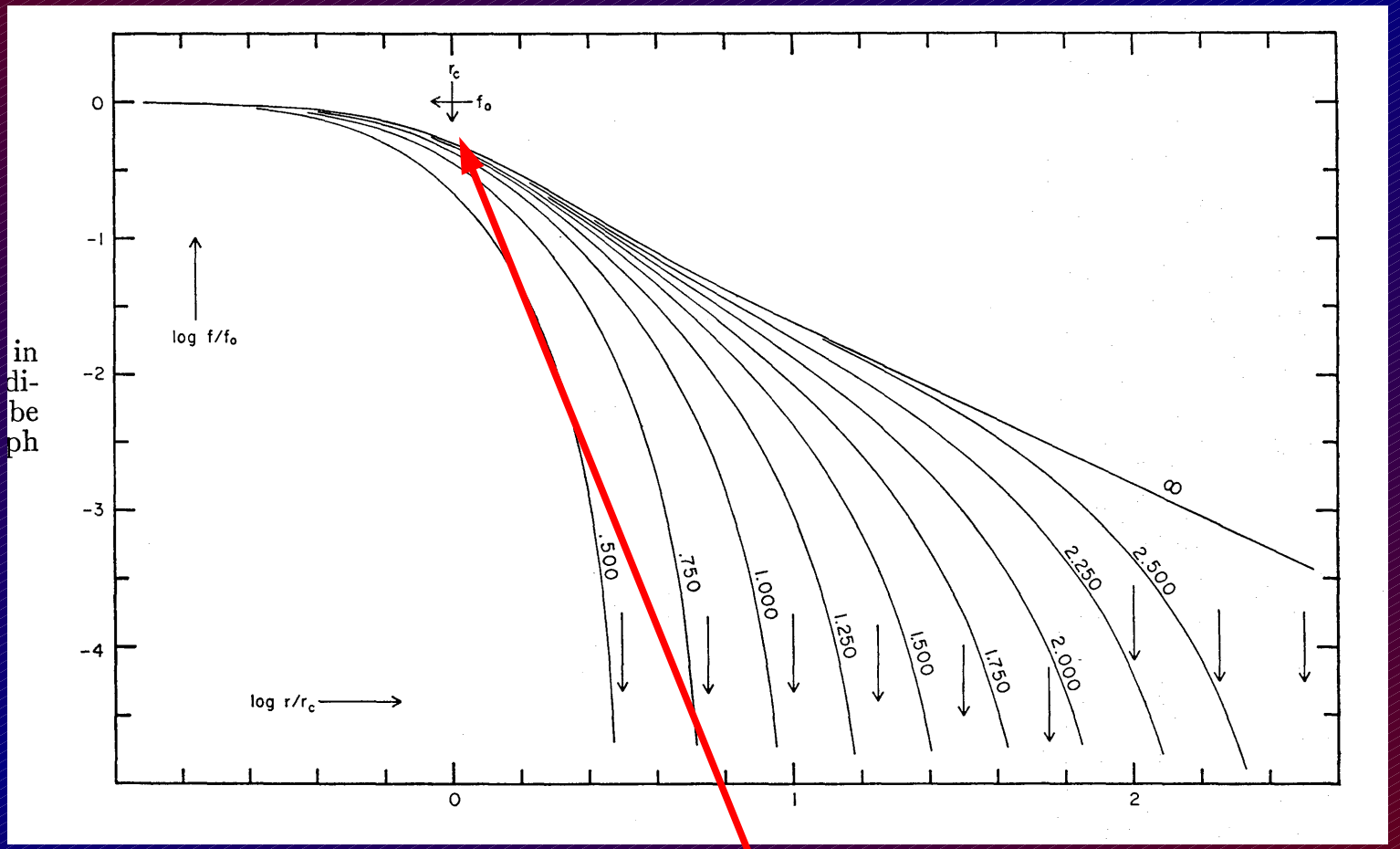
King models

Surface brightness



Projected radius

1-parameter sequence of shapes
+ 2 scale parameters (core radius; total luminosity)

Ivan King

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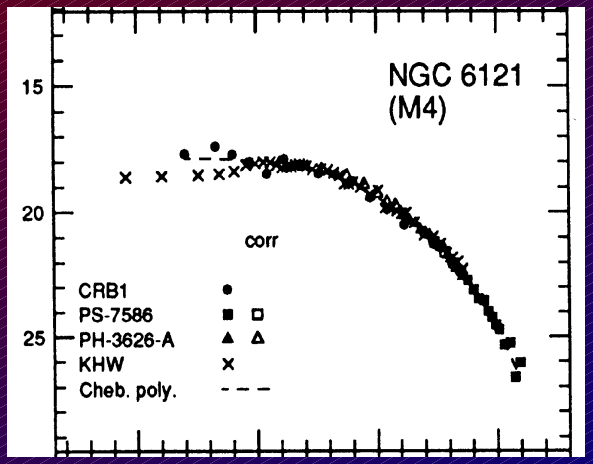
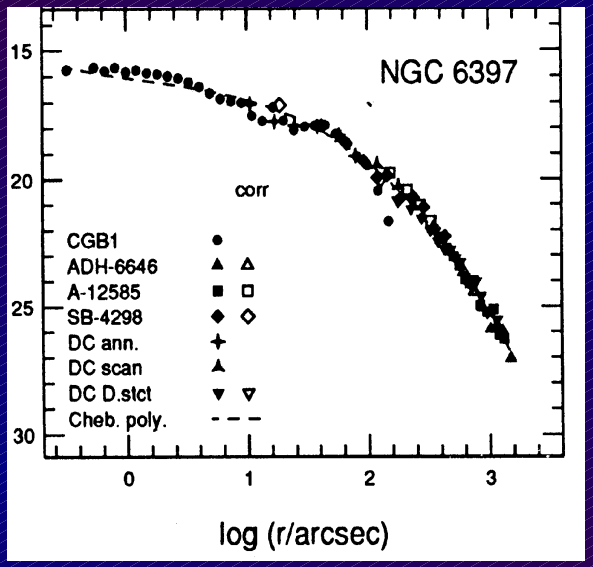
The Surface Brightness Profiles

M4



King profile
Resolvable core radius
Dimmer central SB

NGC 6397



Non-King profile
Unresolvable core
Brighter central SB

Trager et al 1995

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Modelling of M4 and NGC 6397

M4: H & Giersz, 2008, MNRAS, 389, 1858
NGC 6397: G&H, 2009, arXiv:0901.1085v1

Constructed models which approximately fit

- surface brightness profile (*example shortly*)
- velocity dispersion profile
- luminosity function at two radii
- observed binary fraction

Technique:

- Monte Carlo dynamics
- Synthetic stellar and binary evolution

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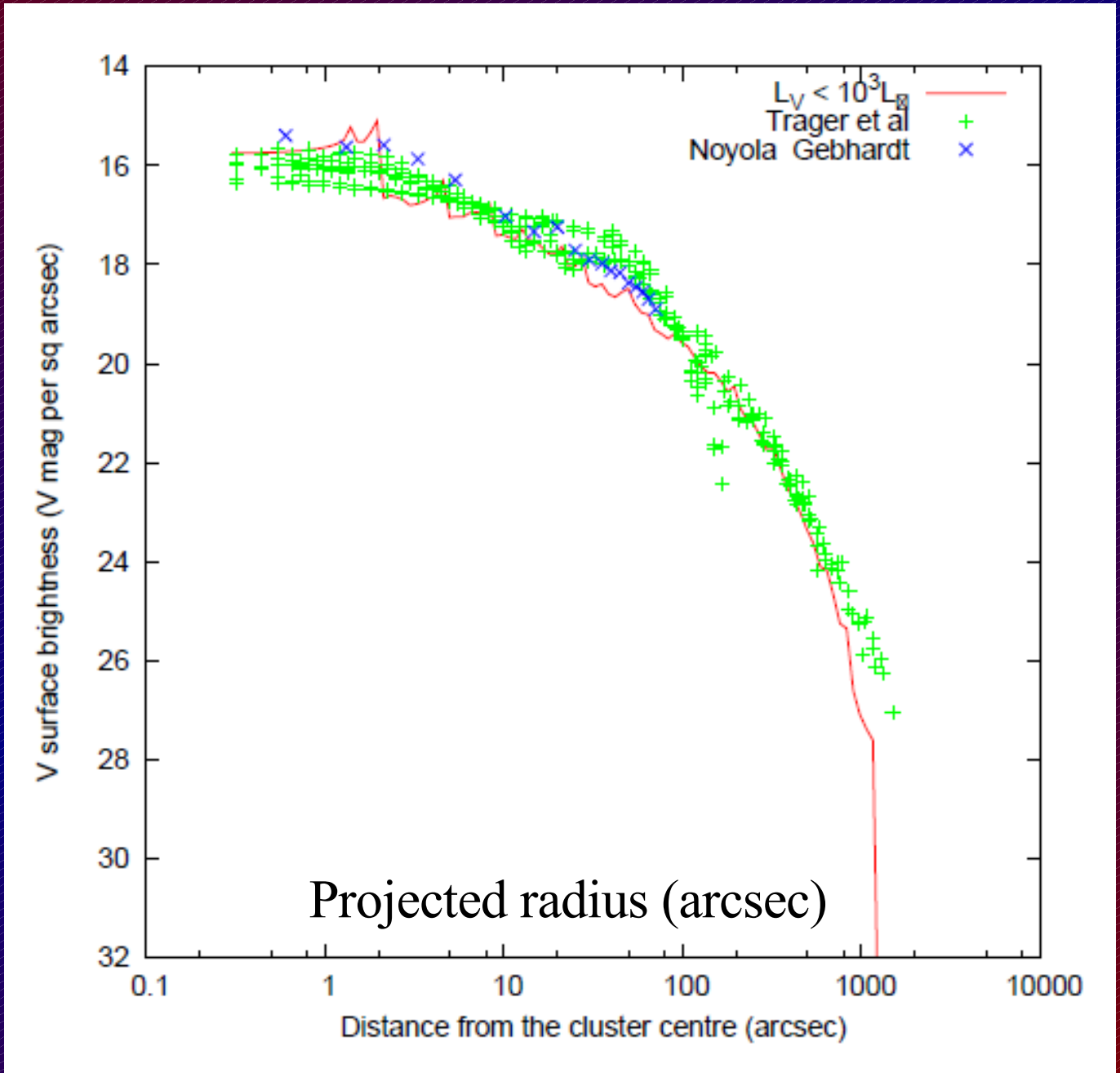
Example: surface brightness profile of NGC 6397 and our model



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Comparison of M4 and NGC 6397

	M4	N6397
Distance from sun (kpc)	1.72	2.6
Distance to Galactic Centre (kpc)	5.9	6.0
Log Mass ($M_\odot$)	4.8	5.0
Half-light radius (pc)	2.2	2.2
Tidal radius (pc)	16	12
Central binary fraction	0.02[a]	0.05[a]
Metallicity [Fe/H]	-1.20	-1.95

These two clusters are very similar, *except* for the surface brightness profile

Various sources (mostly Harris); [a]UBC group

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What determines the surface brightness profile?

1. Core collapse
2. Tidal effects
3. Primordial binaries
4. Stellar-mass black holes
5. Intermediate-mass black holes

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Hypothesis I: Core Collapse (*standard explanation*)

Time scale ∝ relaxation time.

But relaxation times are

0.22Myr (M4) 0.29Myr (NGC 6397)

M4 is evolving faster, but has the "pre-collapse" profile

Conclusion: core collapse is not the explanation

This conclusion is confirmed by the core evolution of our Monte Carlo models:

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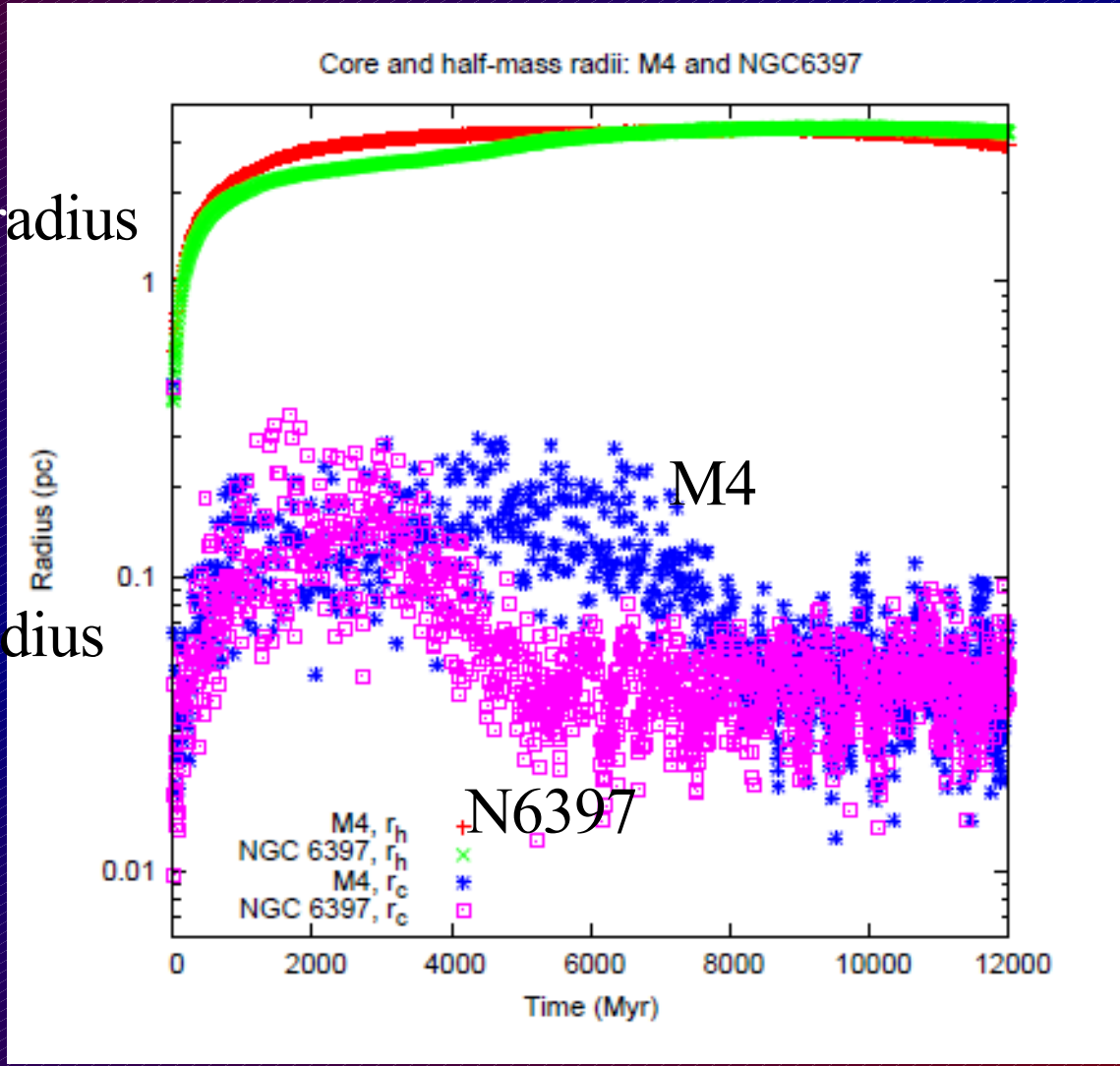
Core evolution of the MC models

Half-mass radius

Core radius



According to our models, both M4 and N6397 are post-core-collapse clusters, with King- and non-King profiles, respectively.

Time

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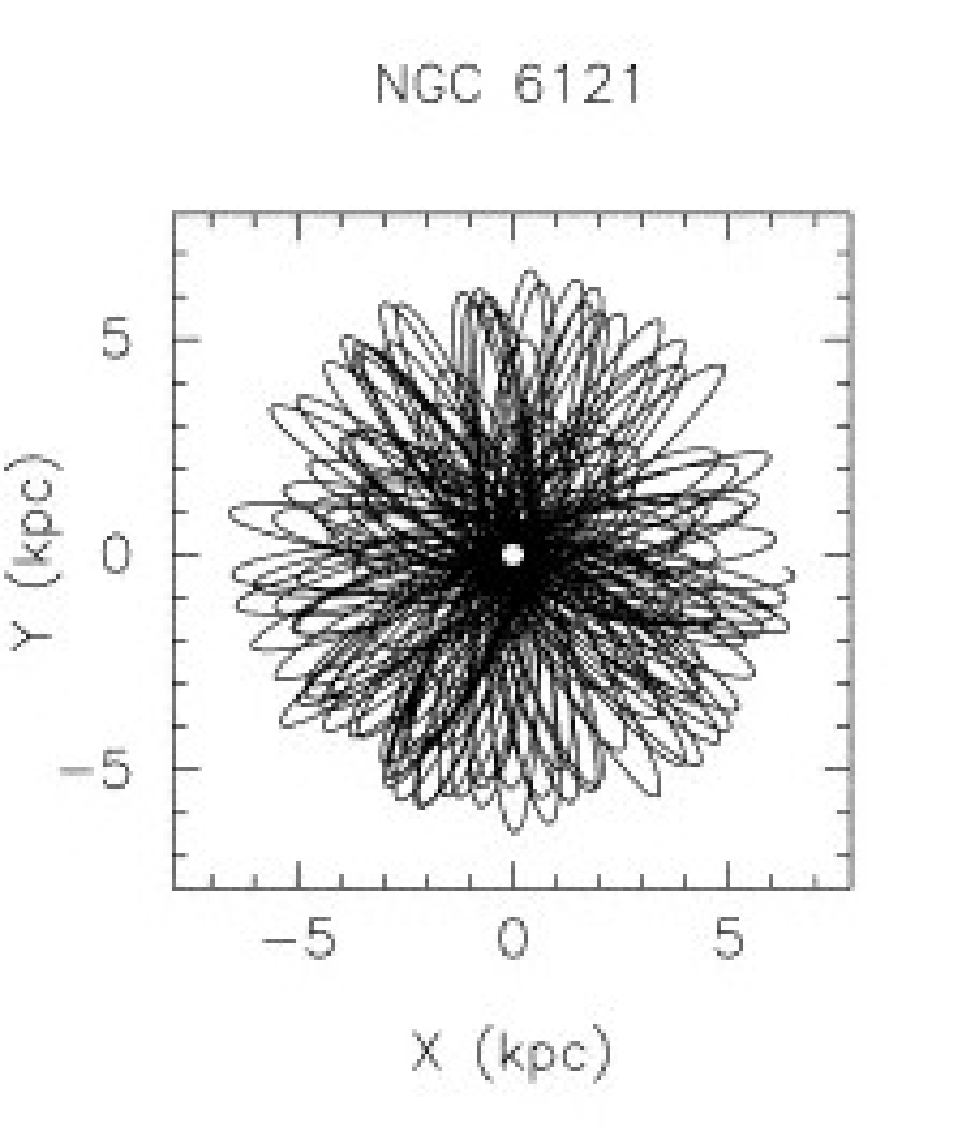
Hypothesis II: Tidal Effects



A galactic orbit for M4

From Dinescu et al 1999

Cluster	Apo	Peri
M4 (N6121)	5.9	0.6
NGC6397	6.3(7.0[a])	3.1(2.6[a])

[a]*Kalirai et al 2007*

M4 has the stronger tidal effects and should evolve faster to core collapse (other things being equal), but it has the "uncollapsed" profile.

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Hypothesis III: Primordial Binaries

More binaries would expand the core.
Does this explain the difference between M4 and N6397?

No: M4 appears to have the smaller binary fraction (Richer et al 2004, Davis et al 2008)

	M4	NGC6397
Centre	~2%	5.1%
Off-centre	~1%	1.2%

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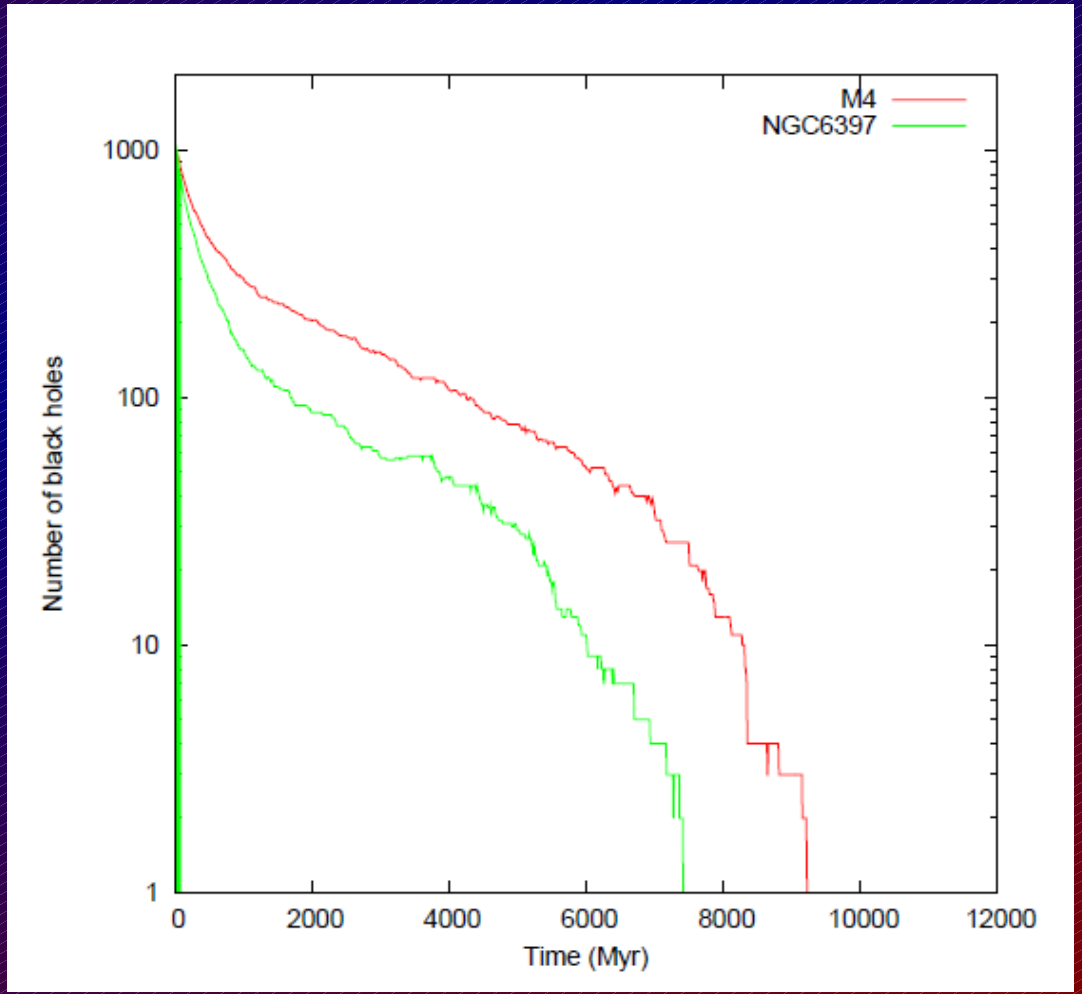
Hypothesis IV: stellar-mass black holes

Can cause core expansion: Merritt et al 2004, Mackey et al 2007

Inoperative in M4 and NGC6397 for last few Gyr



Number of BH

Time (Myr)

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Hypothesis V: Intermediate-Mass Black Holes

IMBH form a cusp, and may expand the core

NGC6397 $M/M_{\odot} < [390,1290]$ (De Rijcke et al 2006)

M4 No literature

Remark: our models account completely for the velocity dispersion of M4 and NGC6397

So why do M4 and NGC6397 have different surface brightness profiles?

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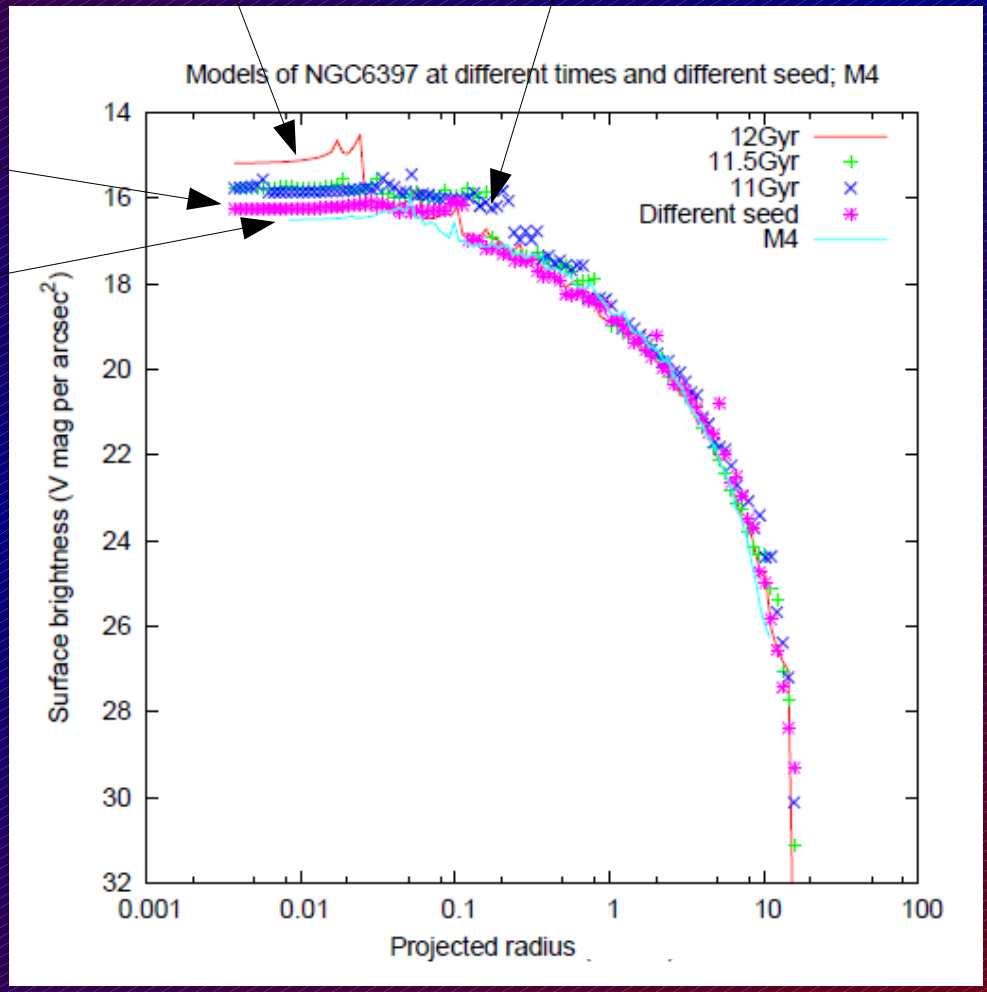
Hypothesis VI: Fluctuations

Basic model

Earlier times (11, 11.5Gyr)

Different seed

M4 model



Surface brightness profiles of

- our model of NGC6397 at 11,11.5,12 Gyr;
- a model of NGC6397 with different seed;
- our model of M4

Conclusion: sometimes NGC6397 has a non-King profile, sometimes it resembles M4

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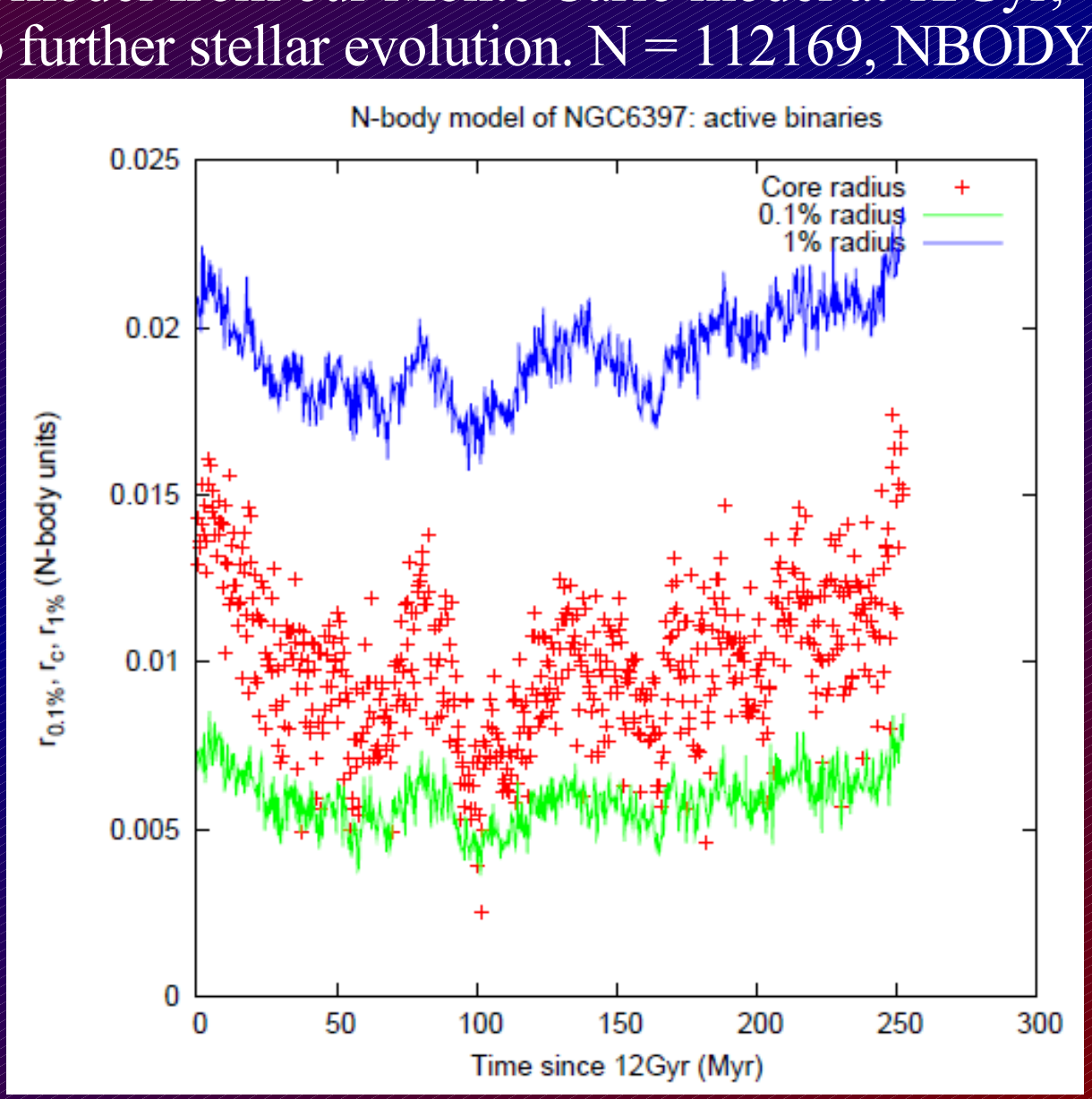
Fluctuations in the core

We constructed an N-body model from our Monte Carlo model at 12Gyr, with active binaries, but no further stellar evolution. N = 112169, NBODY6/GPU

1% Lagrangian radius

(Dynamical) core radius

0.1% Lagrangian radius



Myr since 12Gyr

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Conclusion

The difference between the surface brightness profiles of M4 and NGC6397 is a fluctuation

Remarks

1. These fluctuations are collective, akin to gravothermal oscillations
2. Studying the dynamical evolution of globular clusters is not deterministic