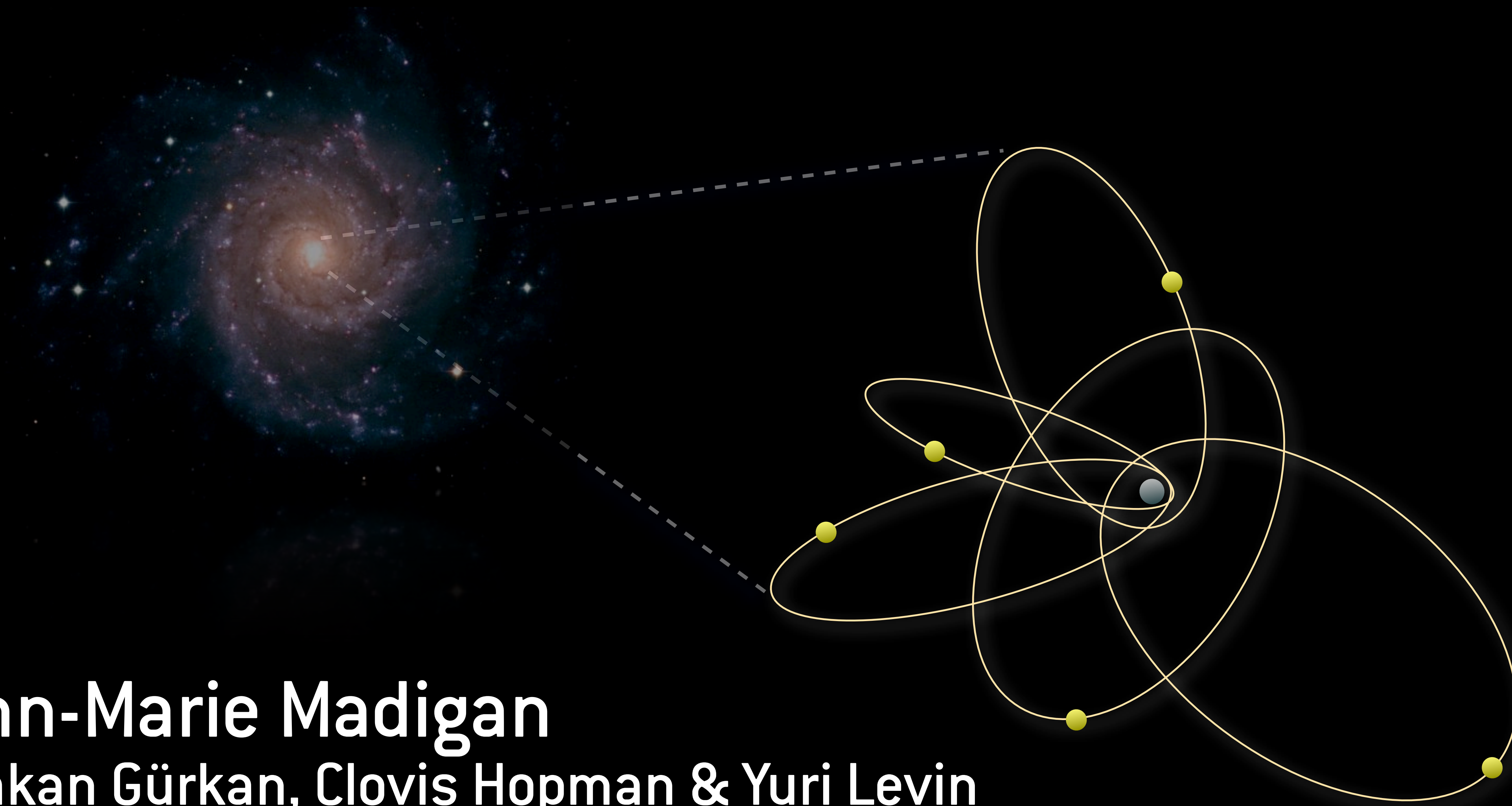
The angular momentum distribution of stars near massive black holes

Sterrewacht Leiden



Ann-Marie Madigan

Atakan Gürkan, Clovis Hopman & Yuri Levin

Resonant Relaxation

Rauch & Tremaine (1996)
Gürkan & Hopman (2007)

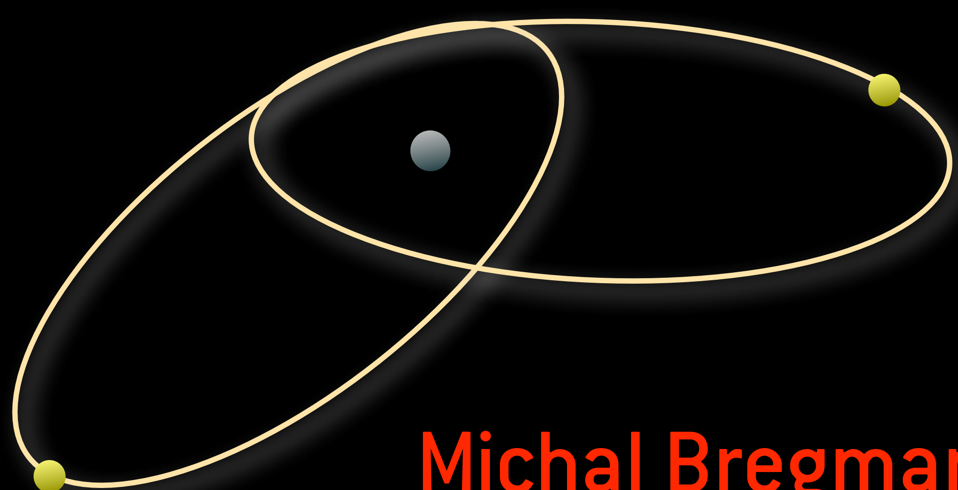
Near-Keplerian Potential:
Stellar orbits retain spatial orientation over many periods

Coherent torques for $t_{\rm orb} << t << t_{\rm prec}$

$$\tau \sim N^{1/2} \frac{Gm}{a} e$$

$$\Delta J = \tau t_{\rm coh}$$

to maximise RR



Michal Bregman
Gabor Kupi
Bence Kocsis

Strategy

1) N-body simulations.

To characterise RR (e).

2) Find statistical model which reproduces features.

Calibrate against N-body simulations.

3) Use model to look at long-term evolution.

1) Non-isotropic steady-state J distribution

- possibly unstable?

2) Another puzzling S-star issue?

N-body Simulations

New special-purpose code:

1) No spurious precession (Wisdom-Holman algorithm)

2) Reduced force calculation (test stars and field stars)

RR Simulations:

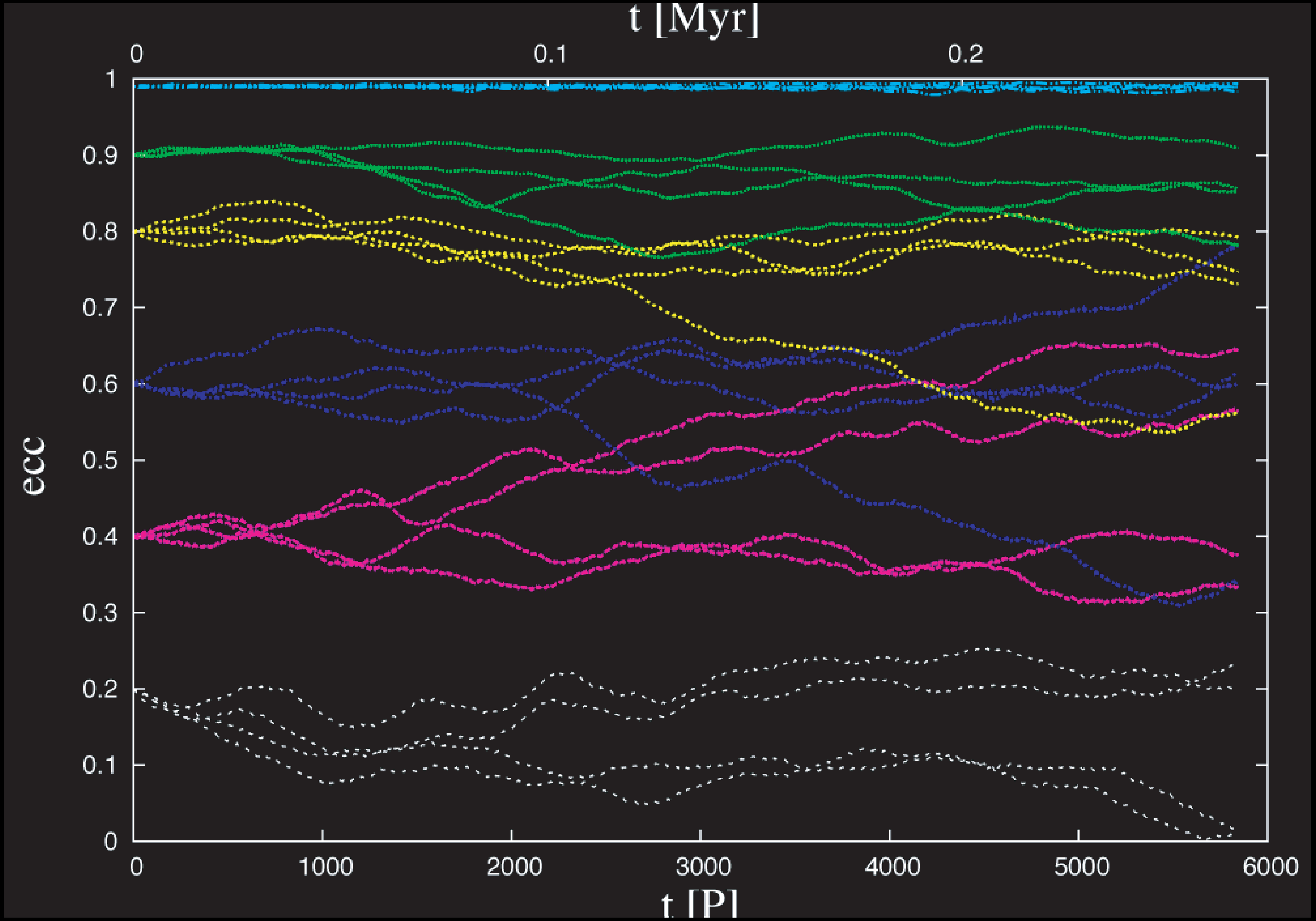
Range of eccentricities (0.01, 0.1, 0.2, 0.3, 0.4, 0.6, 0.8, 0.9, 0.99)

80 test stars for each ecc. dropped into potential:

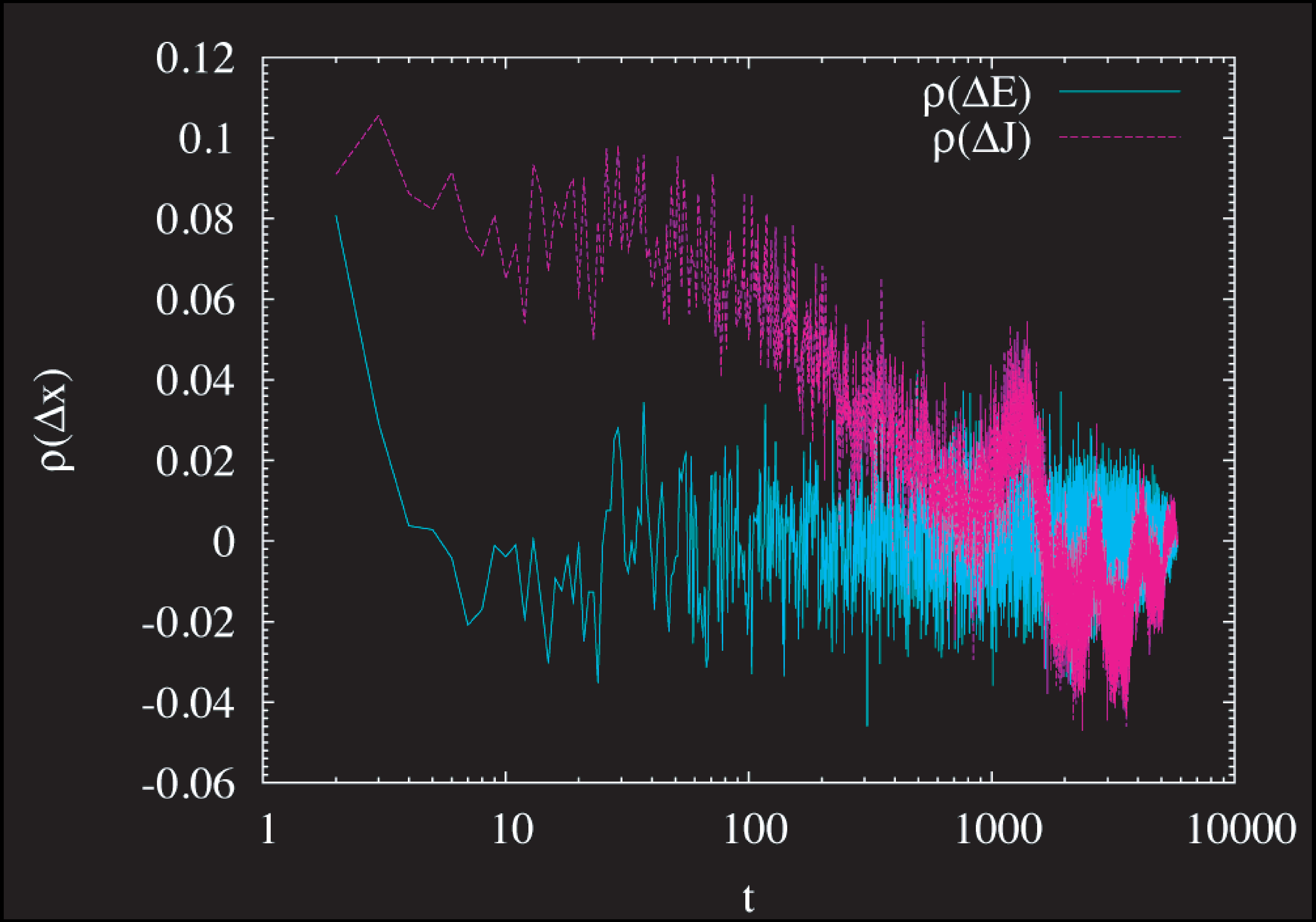
$M_\bullet = 4 \times 10^6 M_\odot$ $\qquad m_s = 10\ M_\odot$

$\rho \propto r^{-7/4}$ $\qquad a_s = 0.01\ pc$

N-body Simulations



Autocorrelation Function



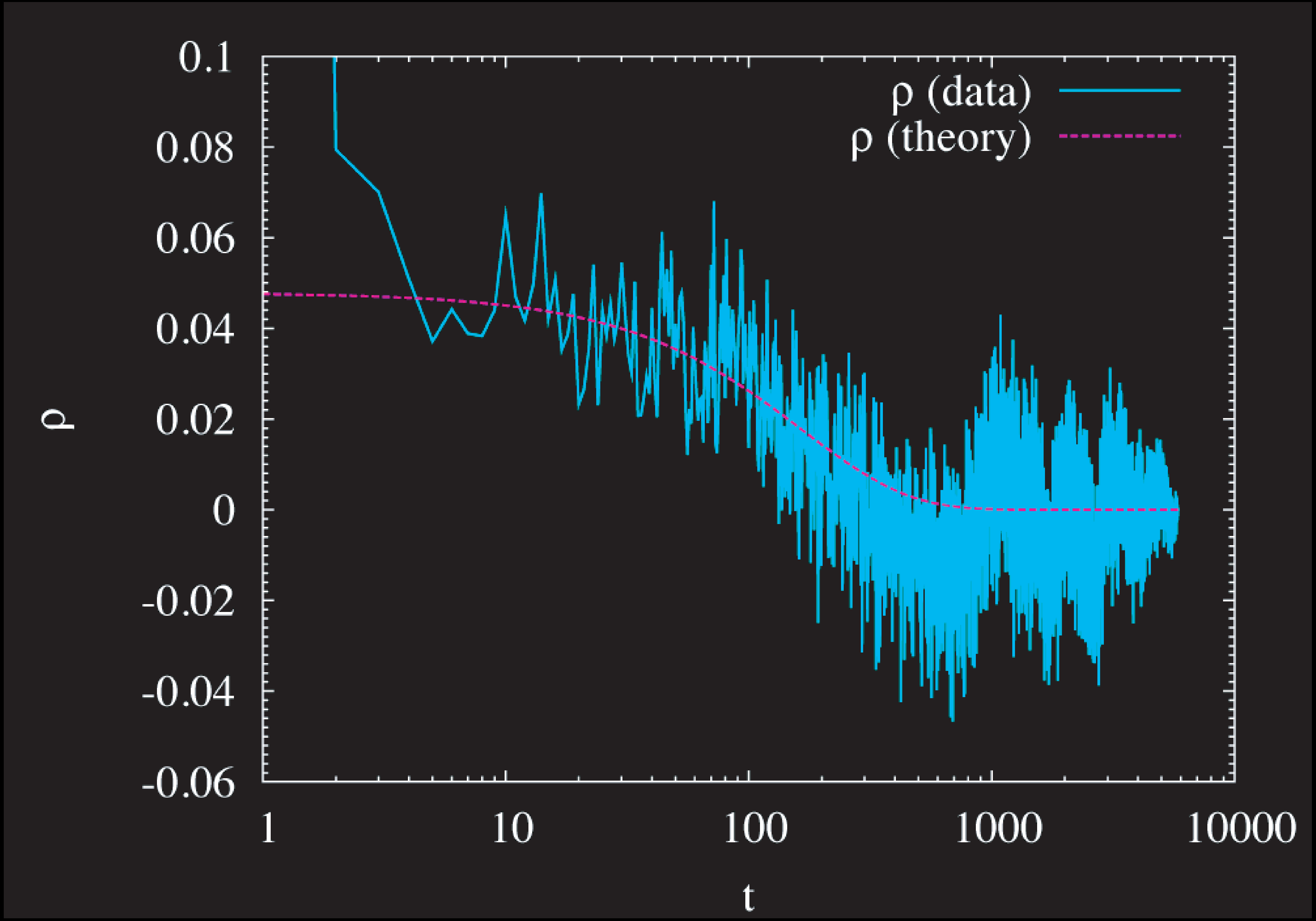
Statistical Description of Resonant Relaxation

ARMA (1,1) model: $$\Delta J_t = \phi \Delta J_{t-1} + \theta \epsilon_{t-1} + \epsilon_t$$

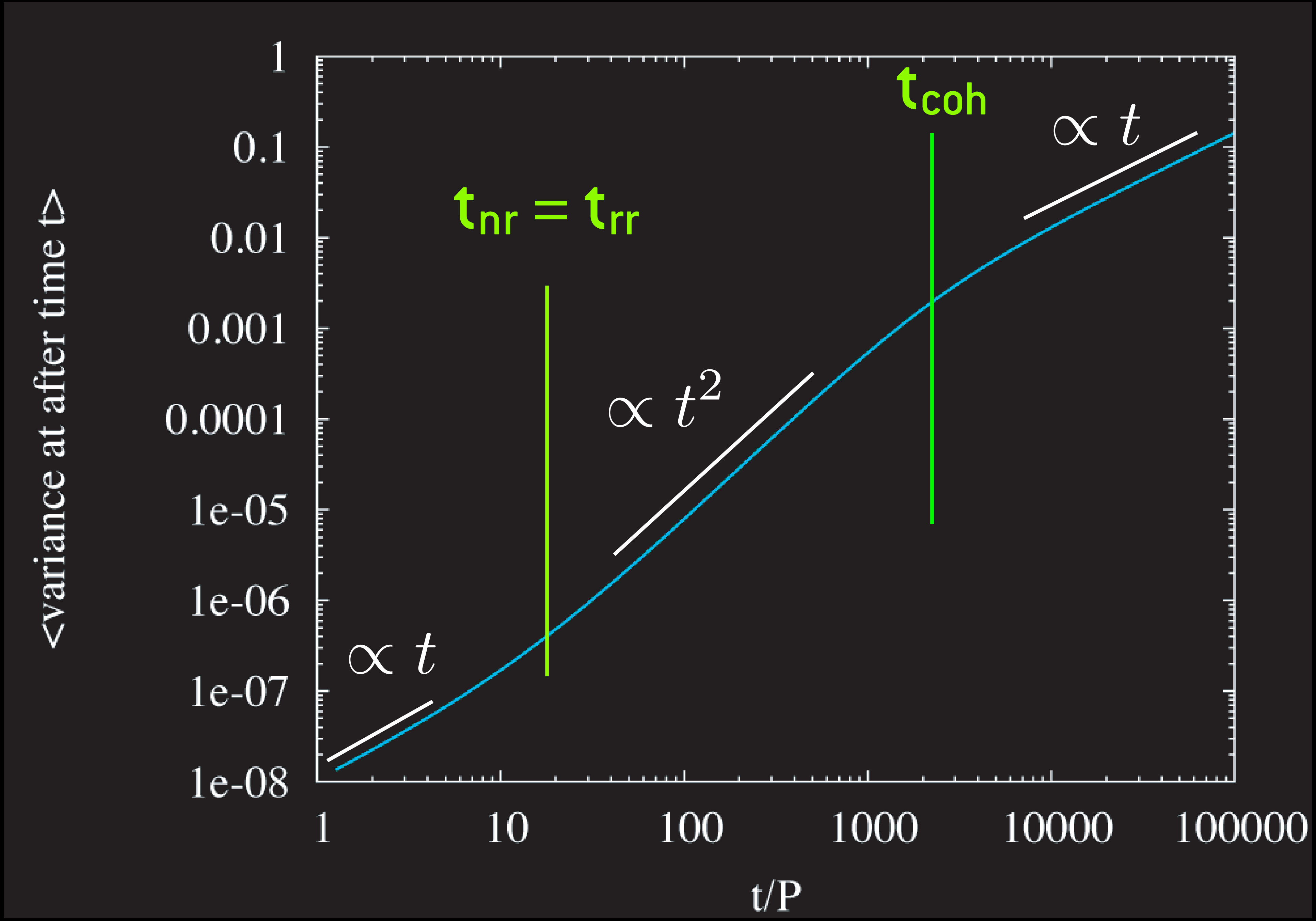
$$\langle \epsilon \rangle = 0$$

$$\langle \epsilon_t \epsilon_s \rangle = \sigma^2 \delta_{t,s}$$

Autocorrelation Function



Variance



<variance at after time t>
t/P
1
0.1
0.01
0.001
0.0001
1e-05
1e-06
1e-07
1e-08
1
10
100
1000
10000
100000
$t_{nr} = t_{rr}$
t_{coh}
$\propto t$
$\propto t^2$
$\propto t$

Strategy

1) For each stellar eccentricity, find (ϕ, θ, σ)

2) Relate quantities to physical parameters of system

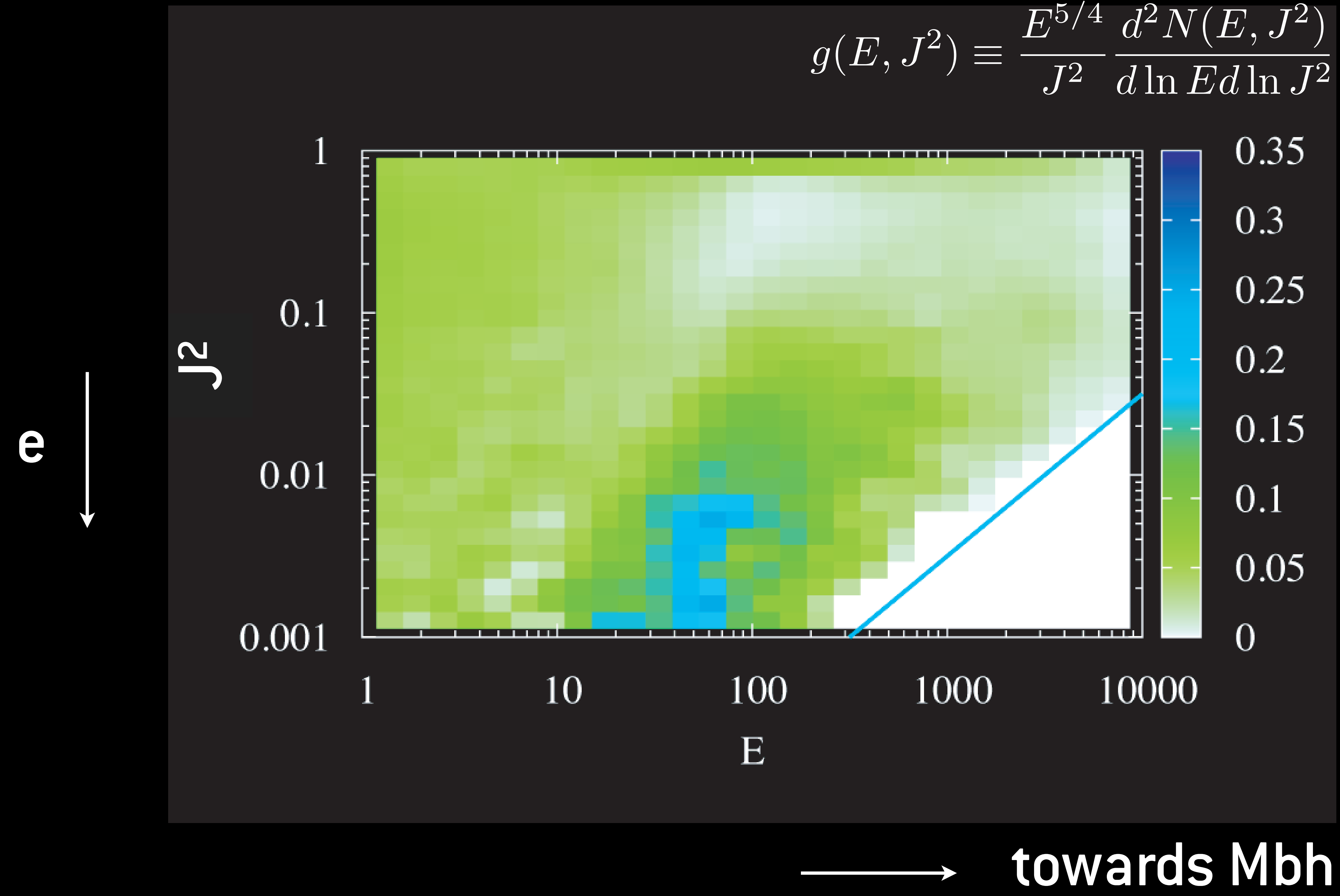
and generalise equations for different time-steps

3) Use in MC code

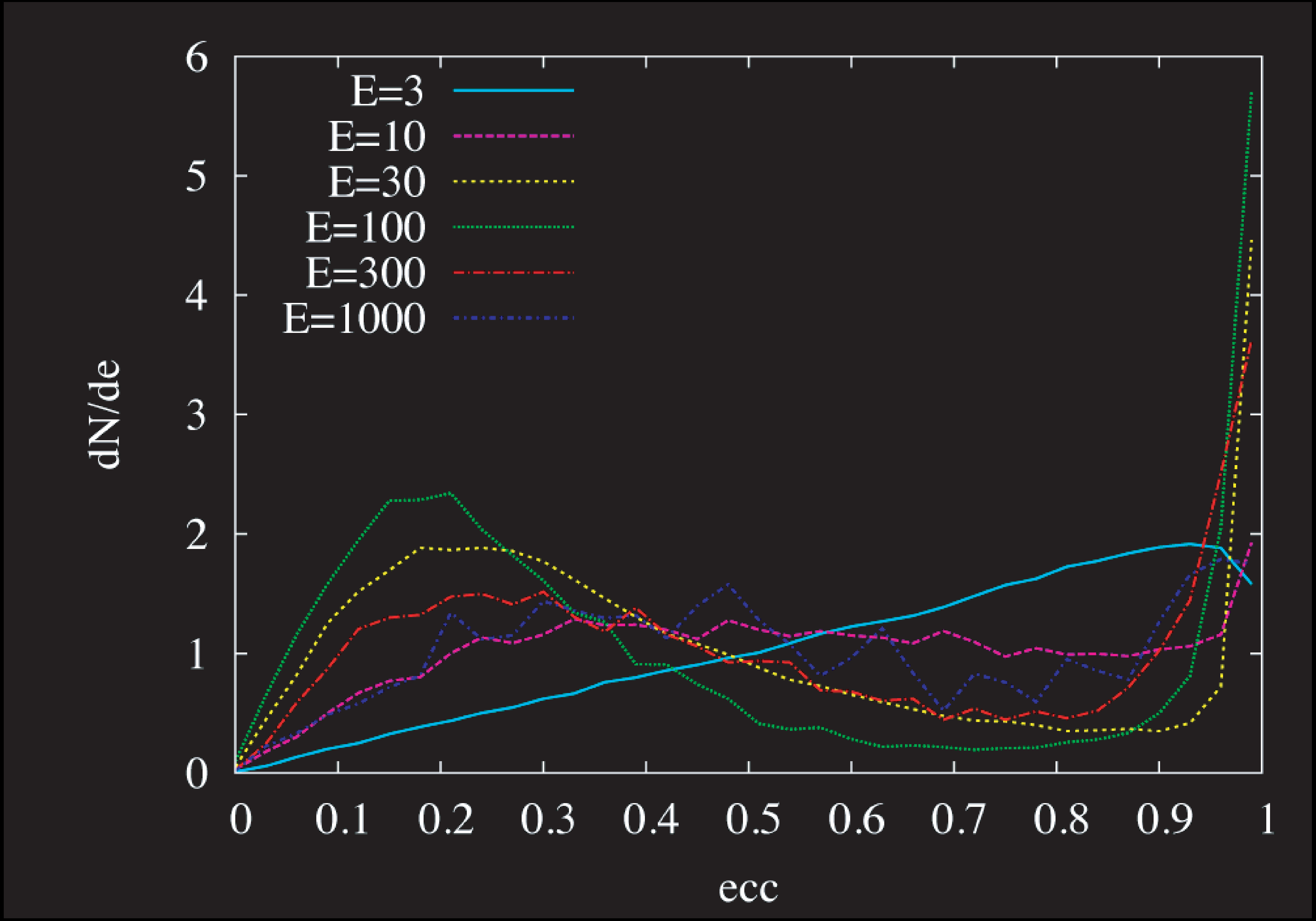
$$\Delta J_t = \phi \Delta J_{t-1} + \theta \epsilon_{t-1} + \epsilon_t$$

ΔE_t 2 body relaxation

Steady-State Distribution



Eccentricity (E)



Unstable system? Tremaine (2005), Polyachenko et al (2007, 2008)

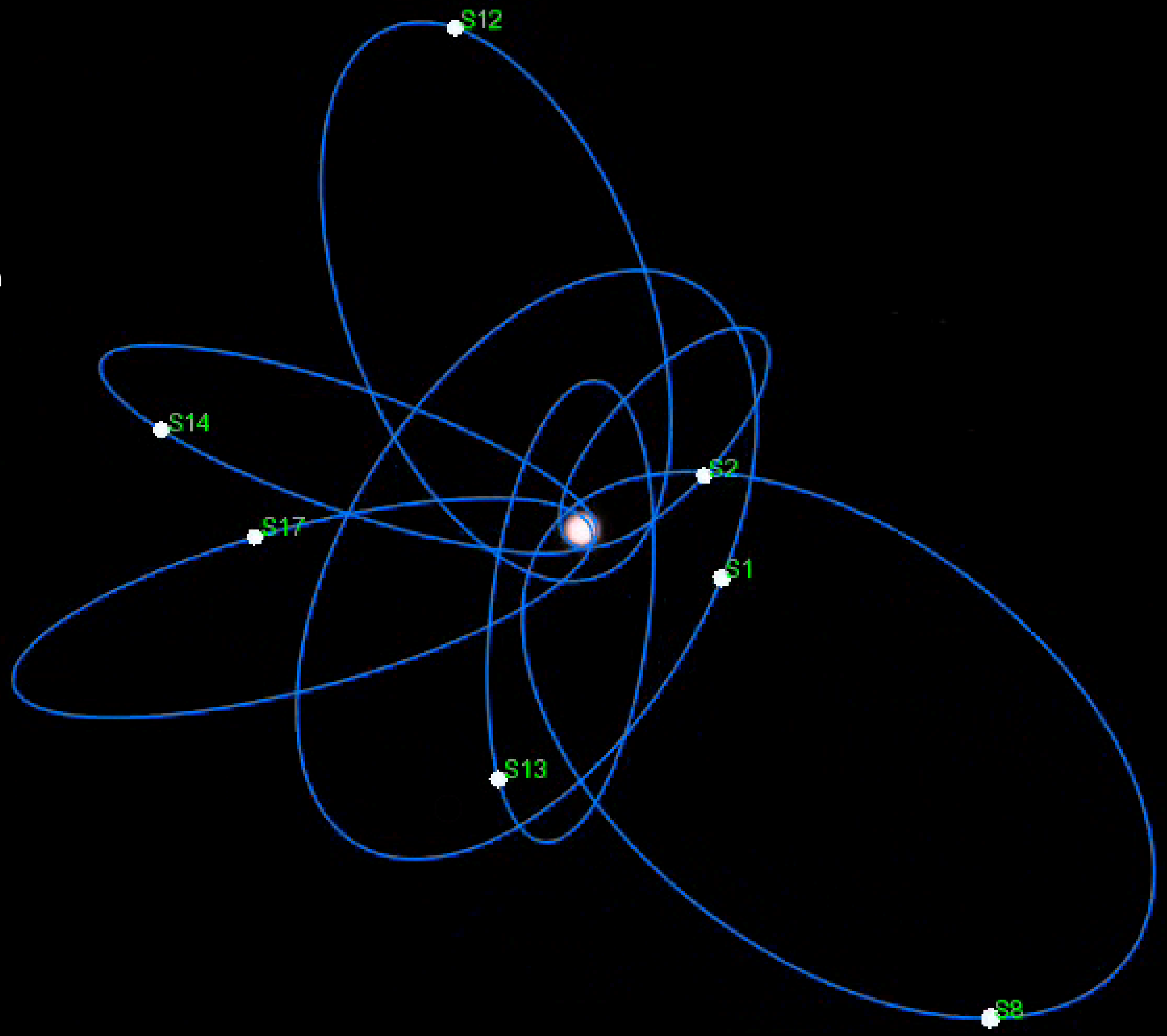
S-stars in Galactic Centre

Formation:
1) In situ?
Molecular Cloud won't survive
2) Outside central pc?
Paradox of Youth

Binary Disruption Scenario:
Perets et al (2007, 2009)
Madigan et al (2009)

Elena Rossi talk (HV stars)

→ Deposits all stars with ecc ~ 0.99



S-stars in Galactic Centre

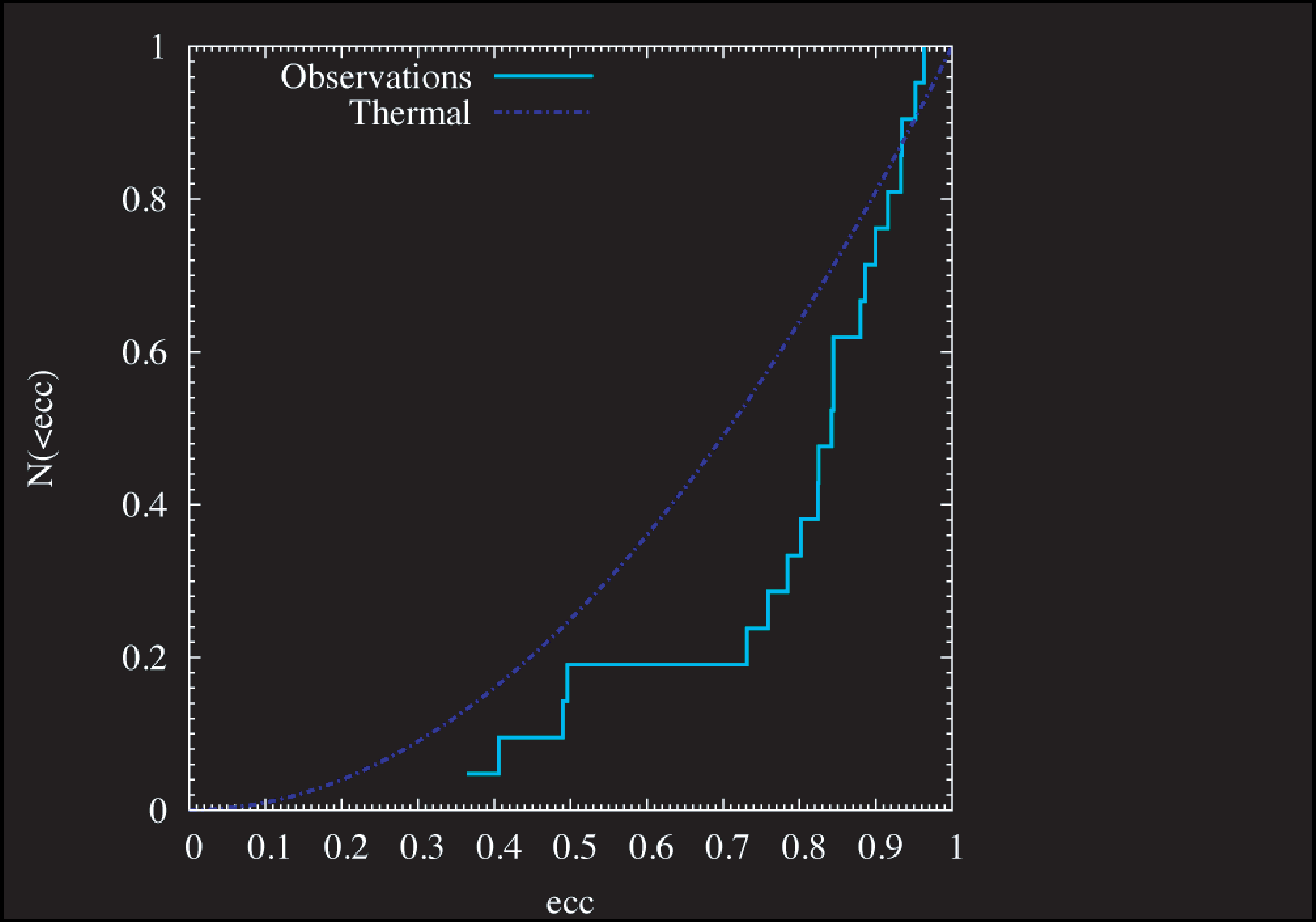
Alessia Gualandris talk

Take semi-major axes of S-stars, evolve in BW potential for two different scenarios:

Continuous: Perets et al (2007)

Burst: Madigan et al (2009)

Continuous



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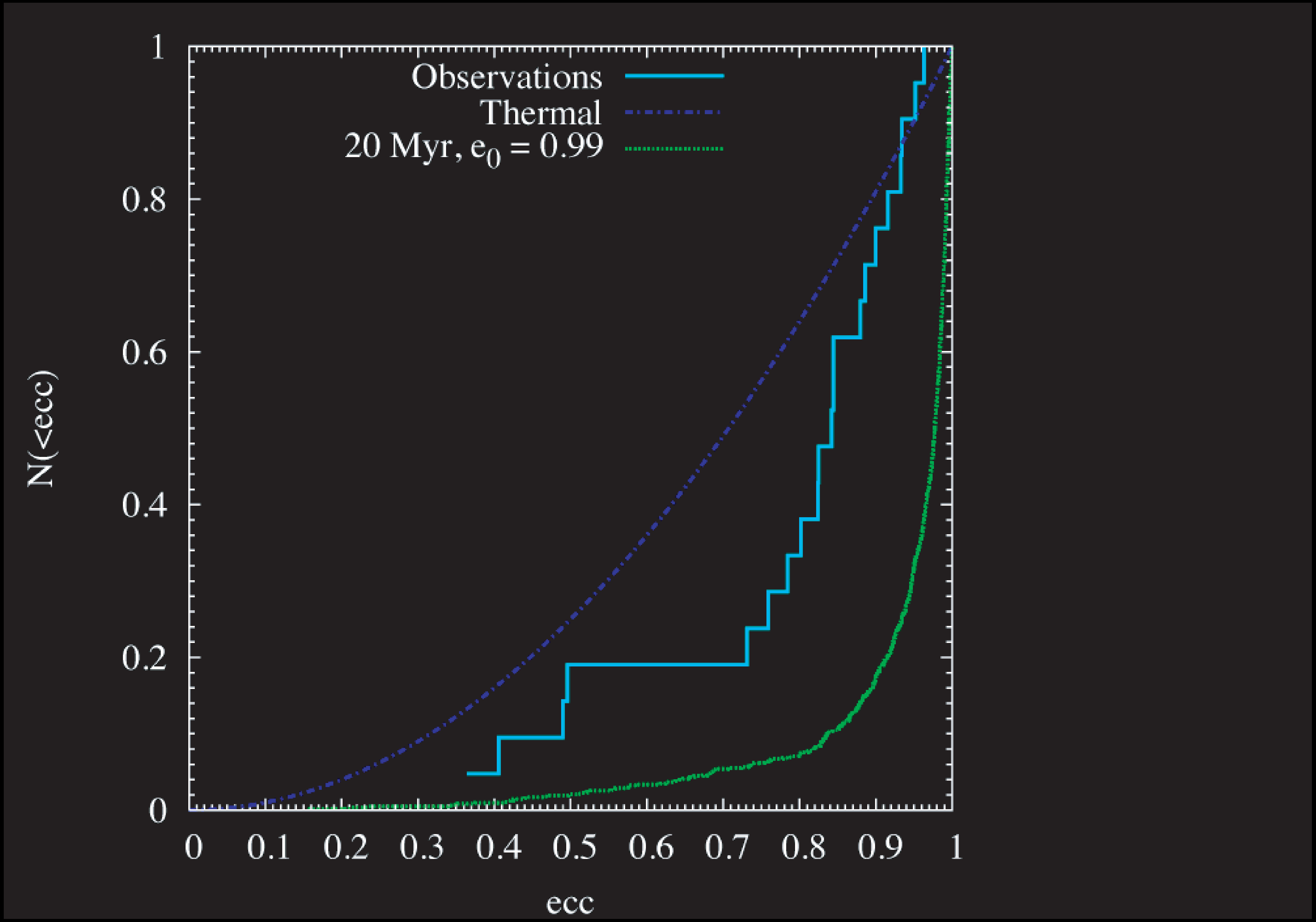
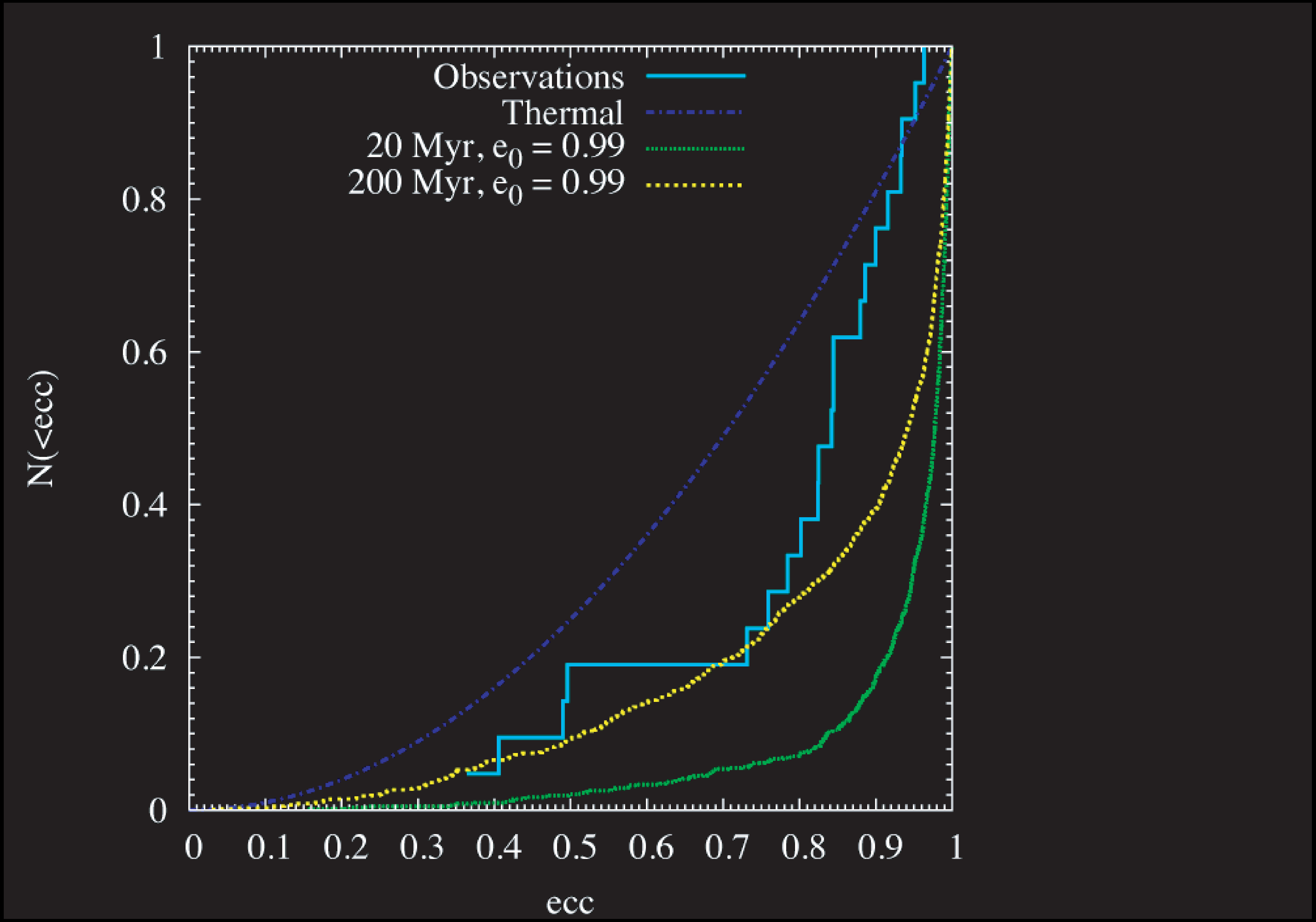


Observations
Thermal
20 Myr, e_0 = 0.99
N(<ecc)
ecc
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1

Continuous



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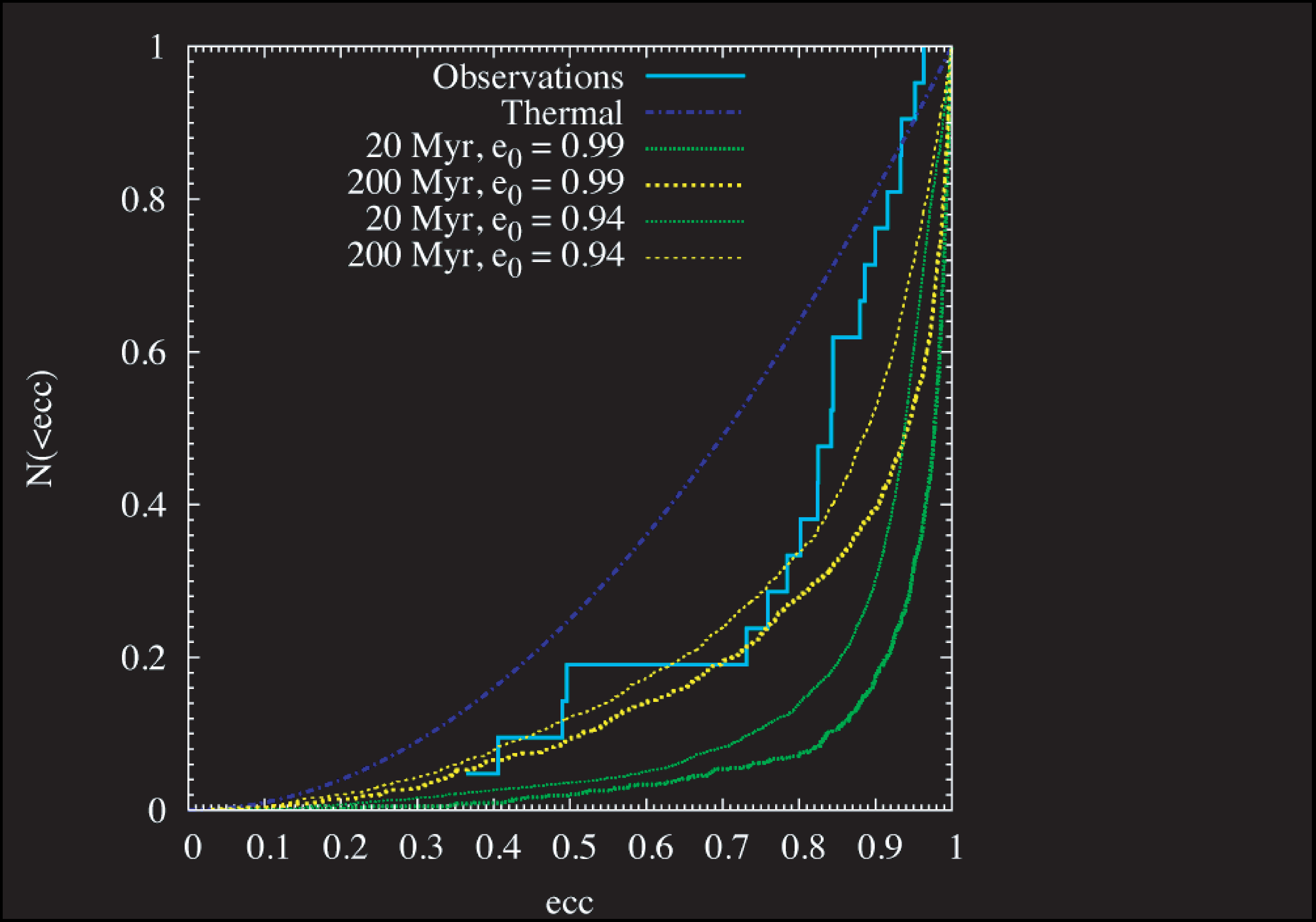
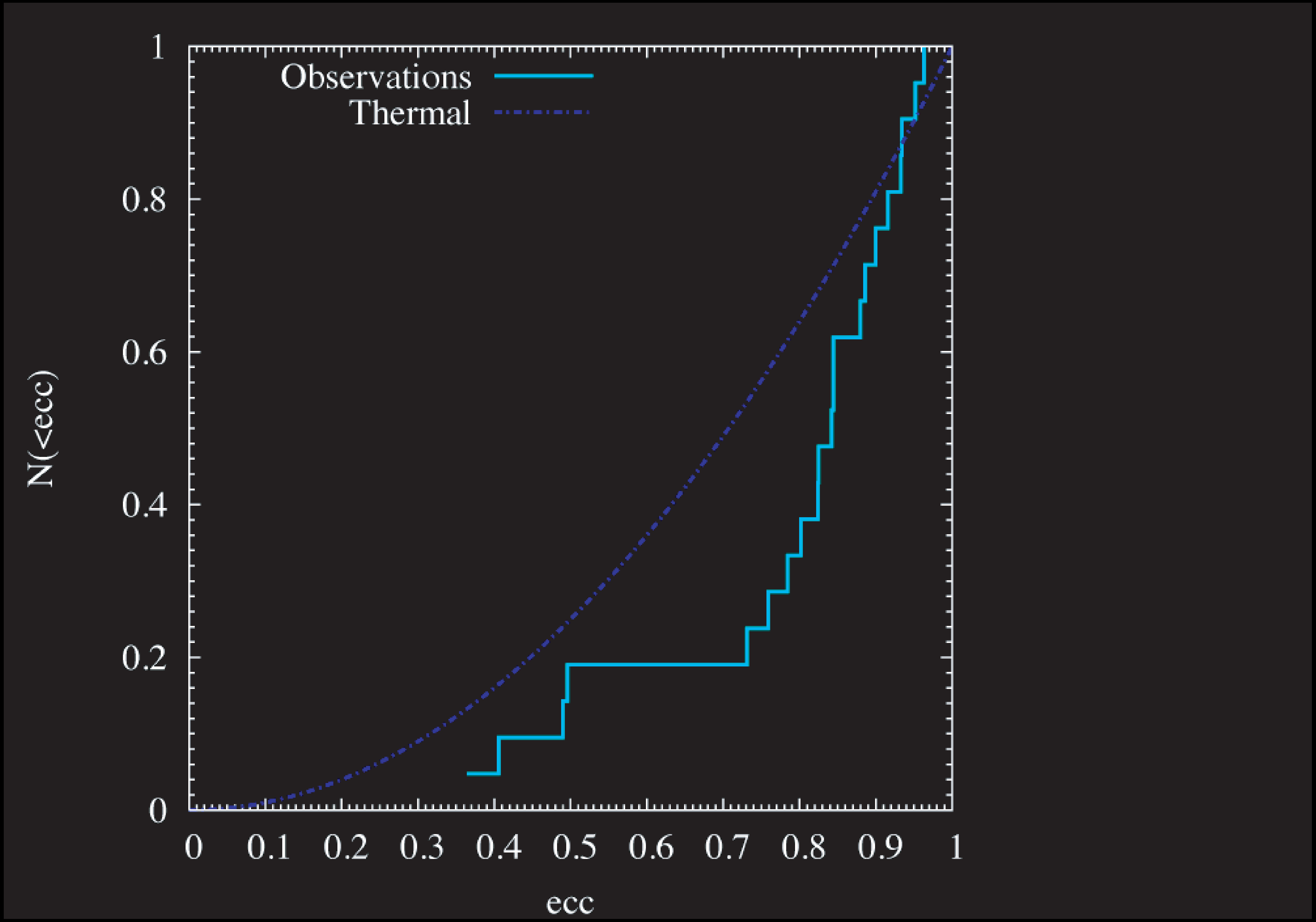
0.4
0.5
0.6
0.7
0.8
0.9
1

Continuous



Observations
Thermal
20 Myr, $e_0 = 0.99$
200 Myr, $e_0 = 0.99$
20 Myr, $e_0 = 0.94$
200 Myr, $e_0 = 0.94$
N(<ecc)
ecc
0
0.2
0.4
0.6
0.8
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Burst



Observations
Thermal
N(<ecc)
ecc
0
0.2
0.4
0.6
0.8
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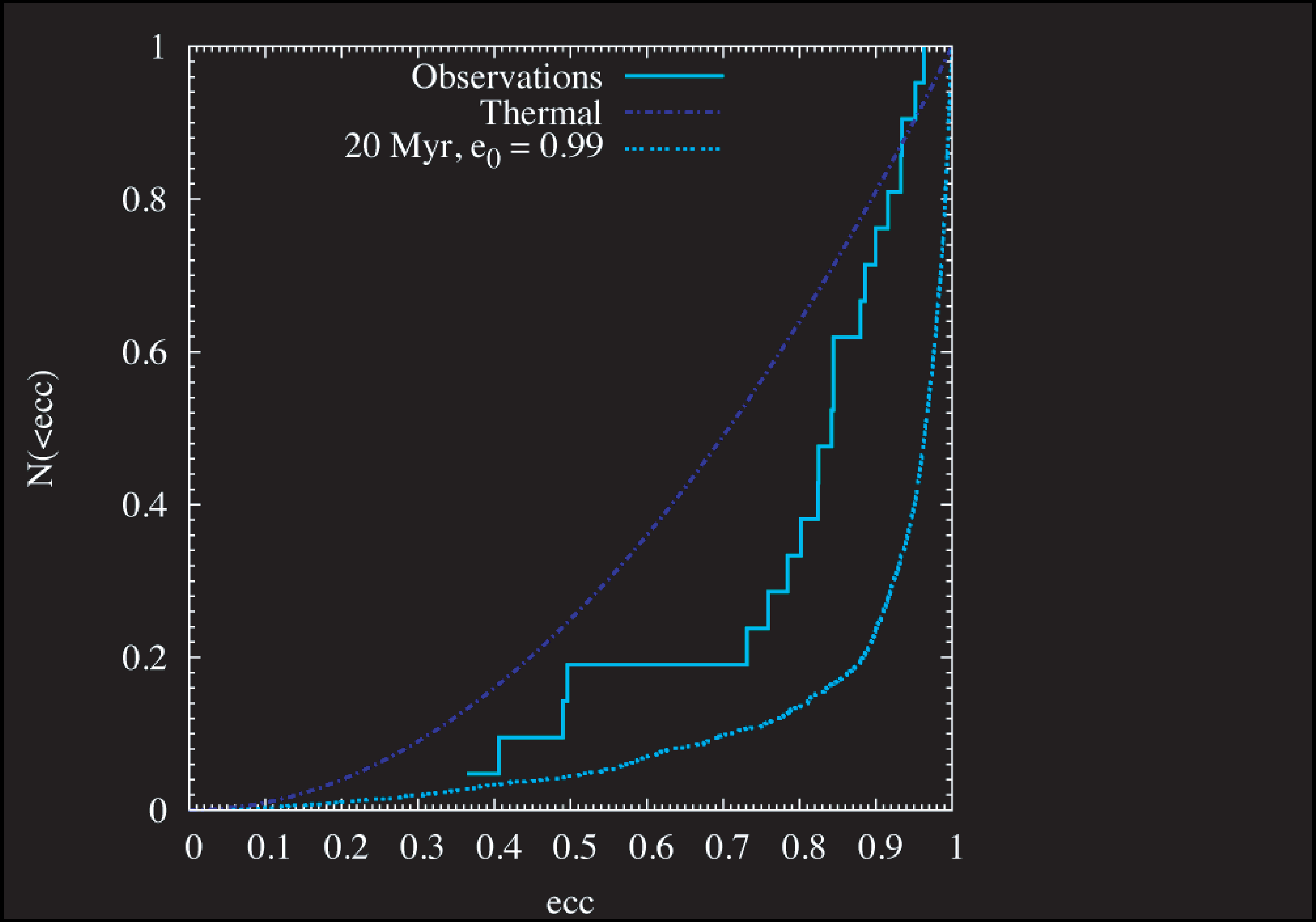
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Burst


Observations
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0.3
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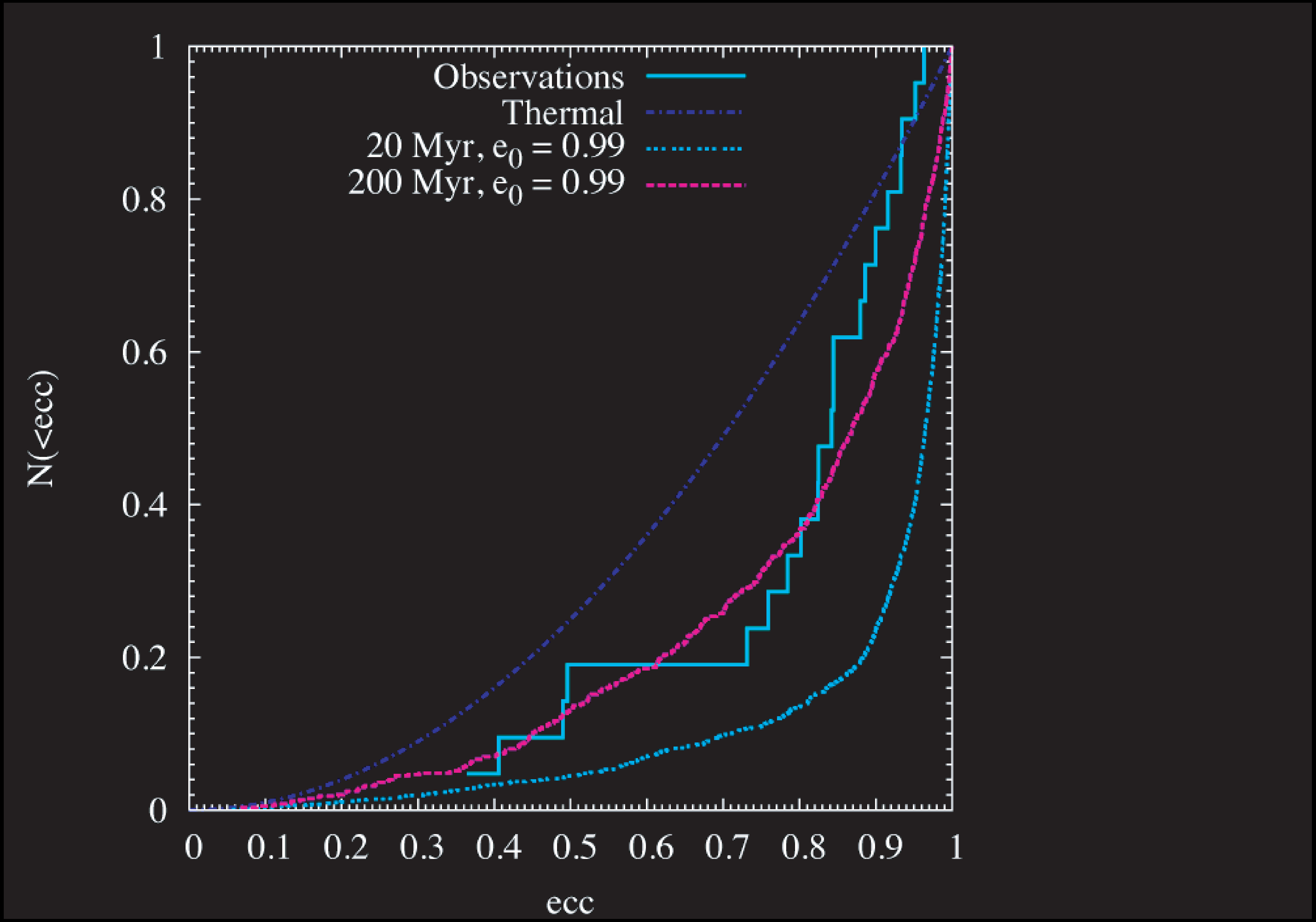
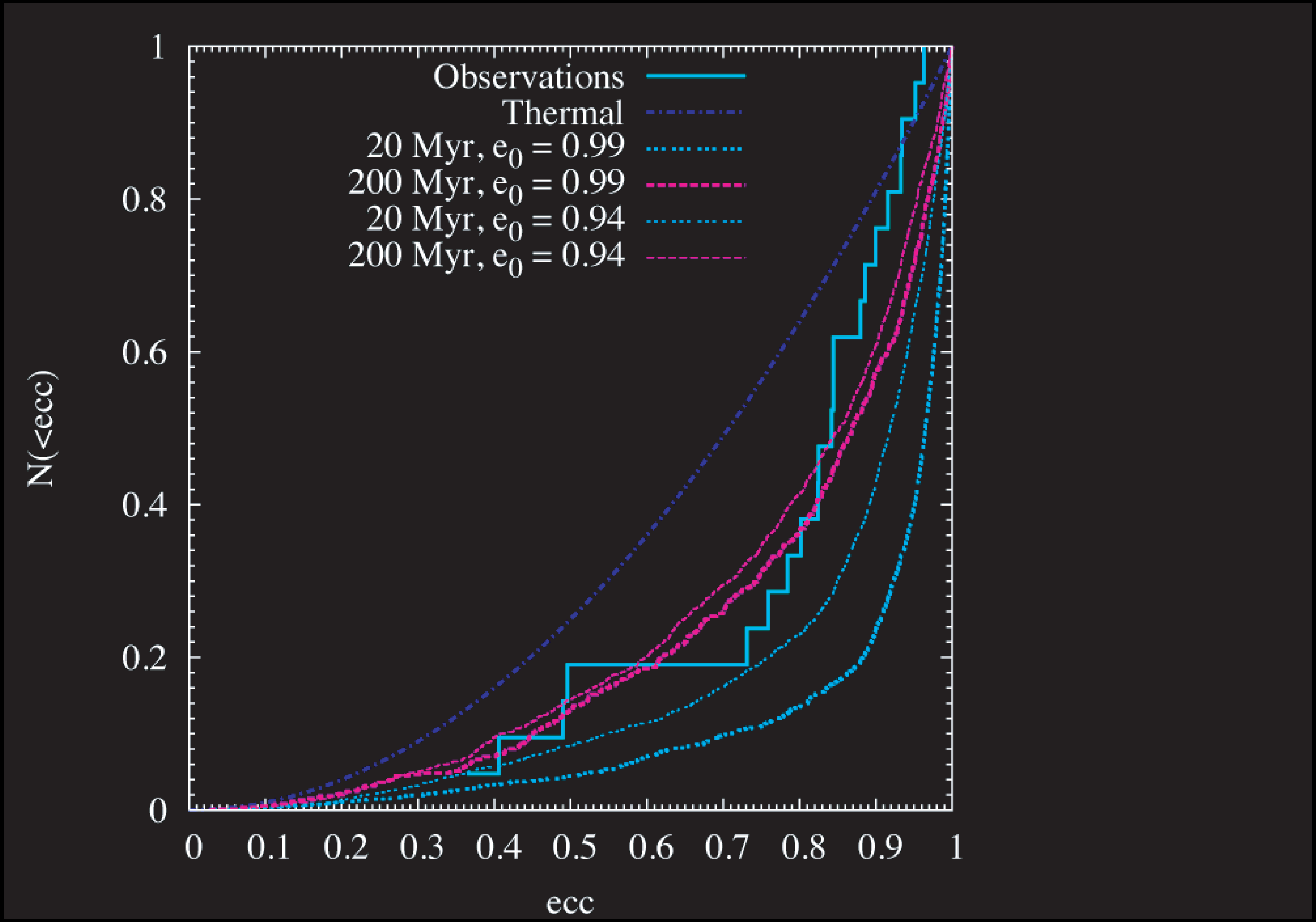
1
0
0.2
0.4
0.6
0.8
1

Burst

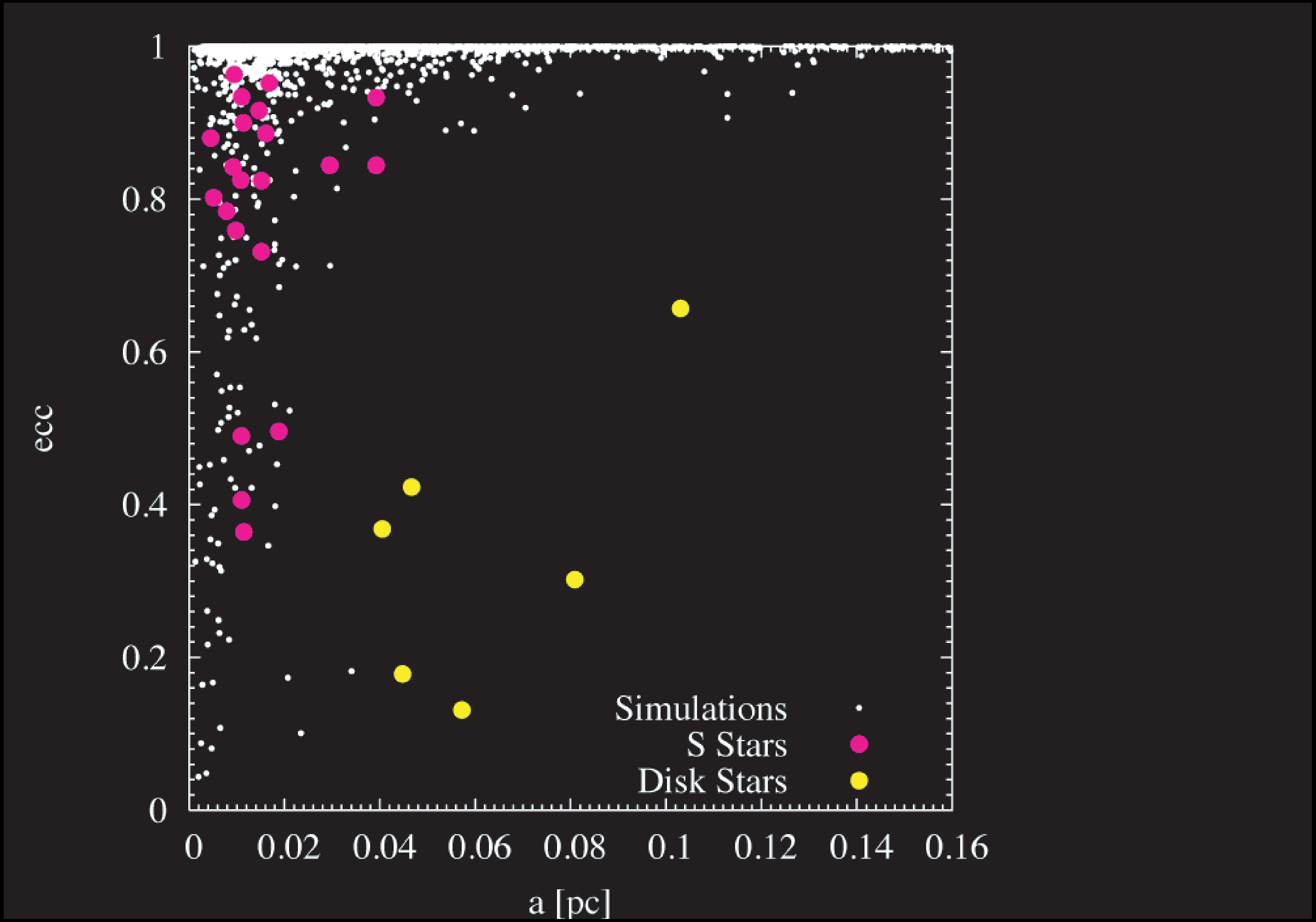


Observations
Thermal
20 Myr, $e_0 = 0.99$
200 Myr, $e_0 = 0.99$
N(<ecc)
ecc
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.2
0.4
0.6
0.8
1

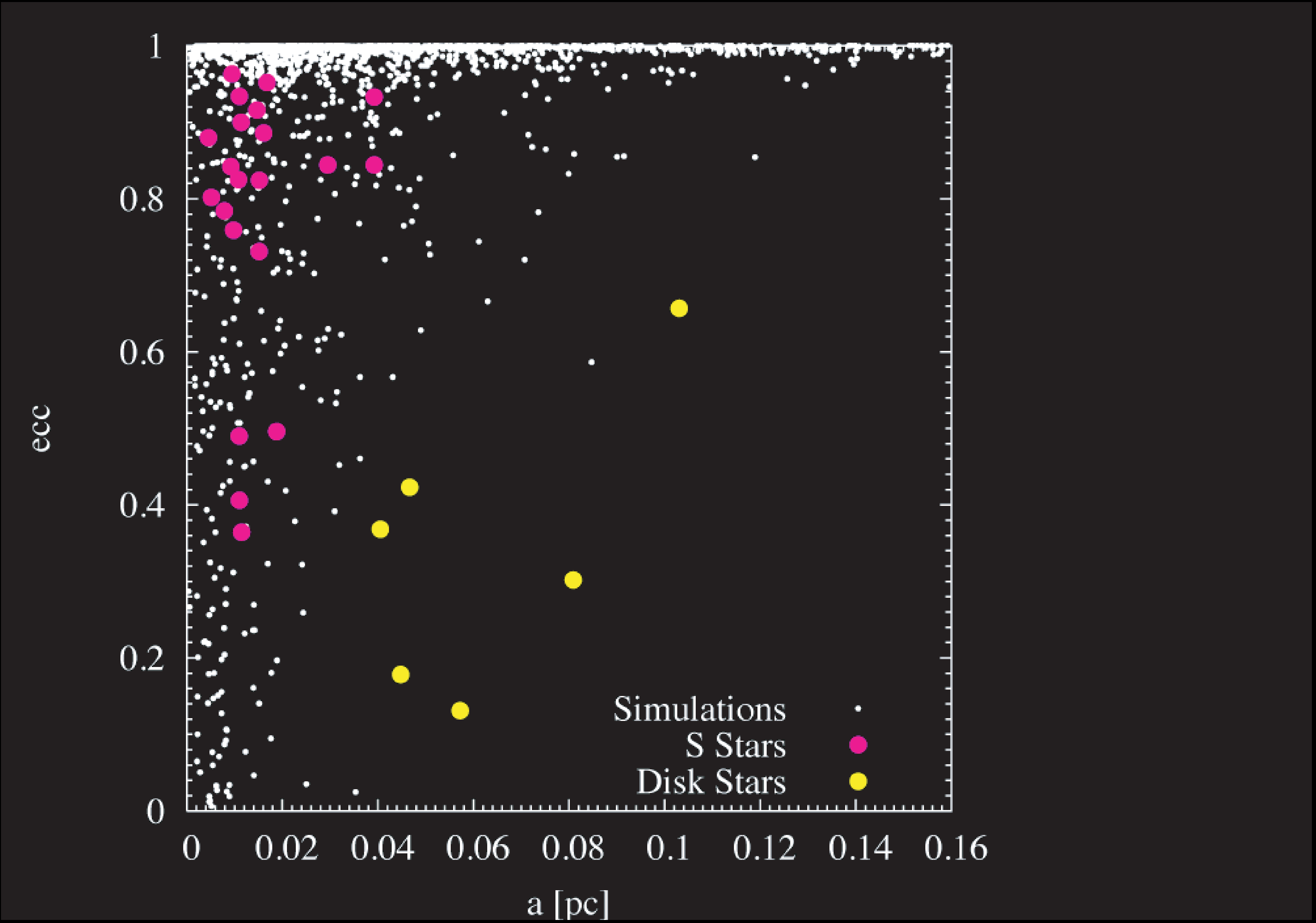
Burst


Observations
Thermal
20 Myr, $e_0 = 0.99$
200 Myr, $e_0 = 0.99$
20 Myr, $e_0 = 0.94$
200 Myr, $e_0 = 0.94$
N(<ecc)
ecc
0
0.2
0.4
0.6
0.8
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

Continuous, 20 Myr

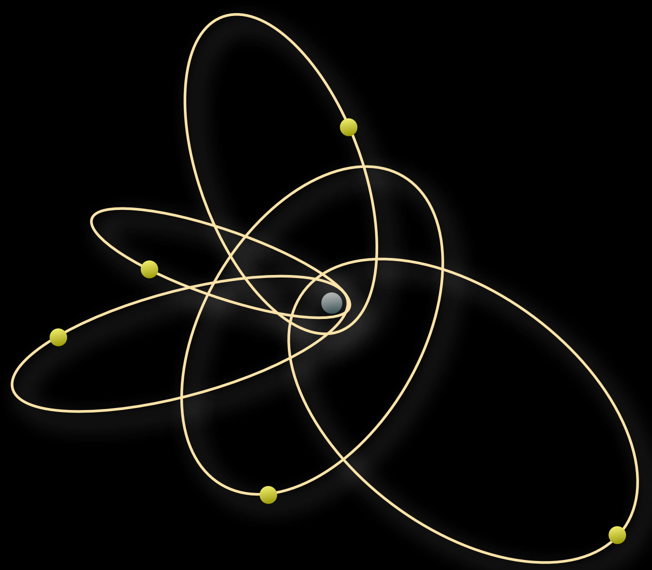


Burst, 20 Myr



1
0.8
0.6
0.4
0.2
0
ecc
0
0.02
0.04
0.06
0.08
0.1
0.12
0.14
0.16
a [pc]
Simulations
S Stars
Disk Stars

Summary



Resonant Relaxation important for galactic nuclei.
Statistical model ARMA (1,1) describes it well

- **Steady-state distribution of stars around massive black holes is not isotropic**

  - possibly unstable? Mark Morris talk

- **Further puzzle for origin of S-star population**

  - dearth of high eccentricities?

- **Tidal disruption and EMRI rates...**

  Cole Miller talk

$$\Delta J_t = \phi \Delta J_{t-1} + \theta \epsilon_{t-1} + \epsilon_t$$