Dynamics of dense star clusters around supermassive black holes with and without central gas disks

Bekdaulet Shukirgaliyev

(Fesenkov Astrophysical Institute, Almaty, Kazakhstan)

Collaborators

STARDISK Project (ARI, NAOC, Fesenkov Astrophysical Institute)

Rainer Spurzem, Peter Berczik, (ARI, NAOC)

Gareth Kennedy, Luca Naso, (NAOC)

Vilkoviskji Emmanuil, Omarov Chingis, Makukov Maxim,

Panamarev Taras, Nurmukhanov Olzhas (FAphI)

АФИФ

NATIONAL ASTRONOMICAL OBSERVATORIES ,CHINESE ACADEMY OF SCIENCES

Fesenkov Astrophysical Institute

FAphI was founded in 1941.

There 5 laboratories in the Institute:

- **Laboratory of Artificial Earth Satellites**
- **Laboratory of Physics of stars and nebulae**
- **Laboratory of stellar dynamics, cosmology and computational astrophysics**
- **Laboratory of Physics of the Moon and planets**
- **Laboratory of active processes in the cosmos**

Overview

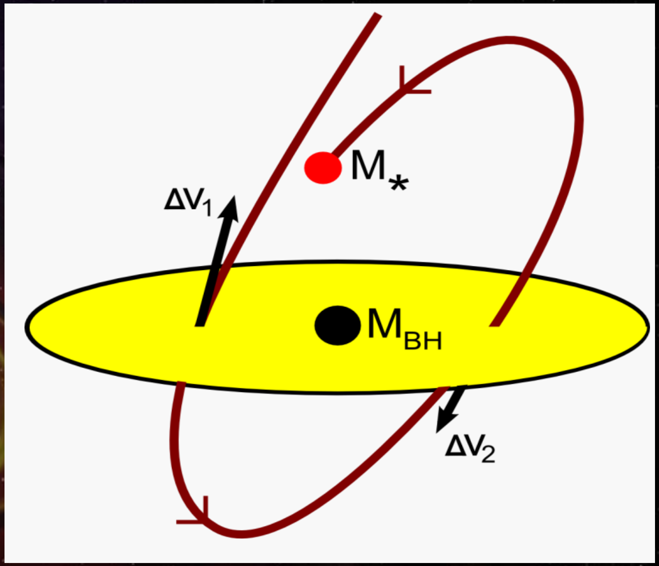
- Background to star-disk interaction
- Method
  - Brief overview of disk and stellar model
  - Concept of the "accretion radius"
- Results from the StarDisk project
  - Capture of stars into MBH via gas disk (effect of particle number , accretion radius and different models of central gas disk)
  - Growth of black holes over time
  - Orbital parametres of captured stars
- Ongoing work

Background

- Require continual mass to be accreted onto a massive black hole (MBH) to generate observed luminosity from a thin disk (need ≈ $1\ M_{sun}$ / year)
- Typical numbers for the galactic centre here are:
  - MBH = $10^8\ M_{sun}$; Schwarzschild radius of $R_S = 2$ AU
  - Mass of the gas disk is a few times $10^6\ M_{sun}$
  - Stellar cusp has mass $10^8\ M_{sun}$ and density [1] $10^6\ M_{sun} / pc^3$ inside the zone of influence $R_{ZOI} = 10.75$ pc
- Known relationship between the black hole mass and the velocity dispersion of the bulge implies a physical link (M-σ relationship) [2]

Background to modelling

- Combine stellar dynamics of solar type stars with a constant gas disk
- Each time the star crosses the disk a small amount of energy is transferred to the disk, thus decaying the orbit of the star and ensuring further passages



- Previous work from STARDISK Project [3]:
  - Examined the increase in star accretion rates due to a gas disk
  - Used scaling relations to compensate for the (presently) unattainable number of stars to model two-body relaxation
  - Accretion disk increased the capture of stars by a factor of ~ 4

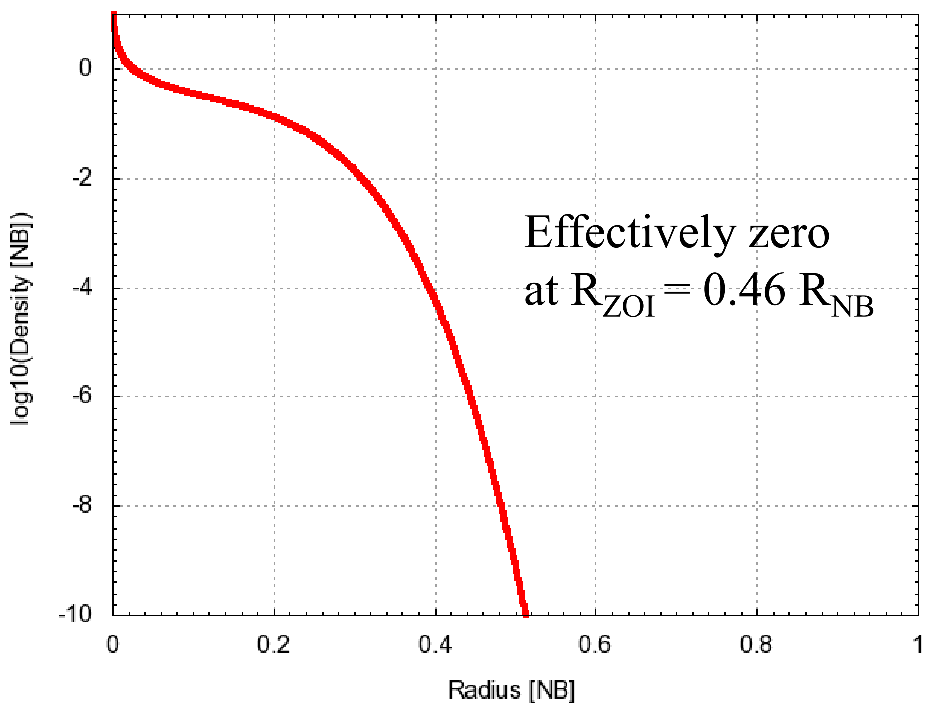
Numerical method

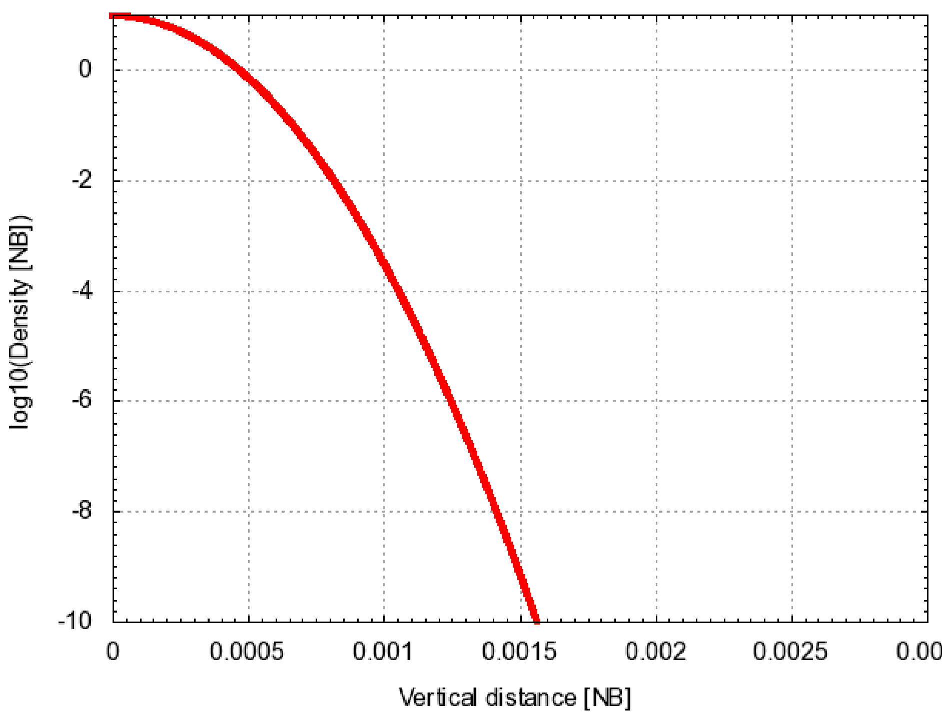
- We use a modification of the PhiGRAPE-GPU code
- This code now runs on GPU rather than GRAPE cards and is described in detail in Just et al 2012 [3]
- Stars are removed at the accretion radius if they meet:

  $r < r_{\rm acc}$ and $V_\star^2 < k_{\rm acc} v_{\rm circ}^2$
- Model star cluster of total mass 10 M_{BH}
- Disk mass is fixed as 0.1 M_{BH}
- M_{BH} is fixed at 10^8 M_{sun} for these results

Disk model

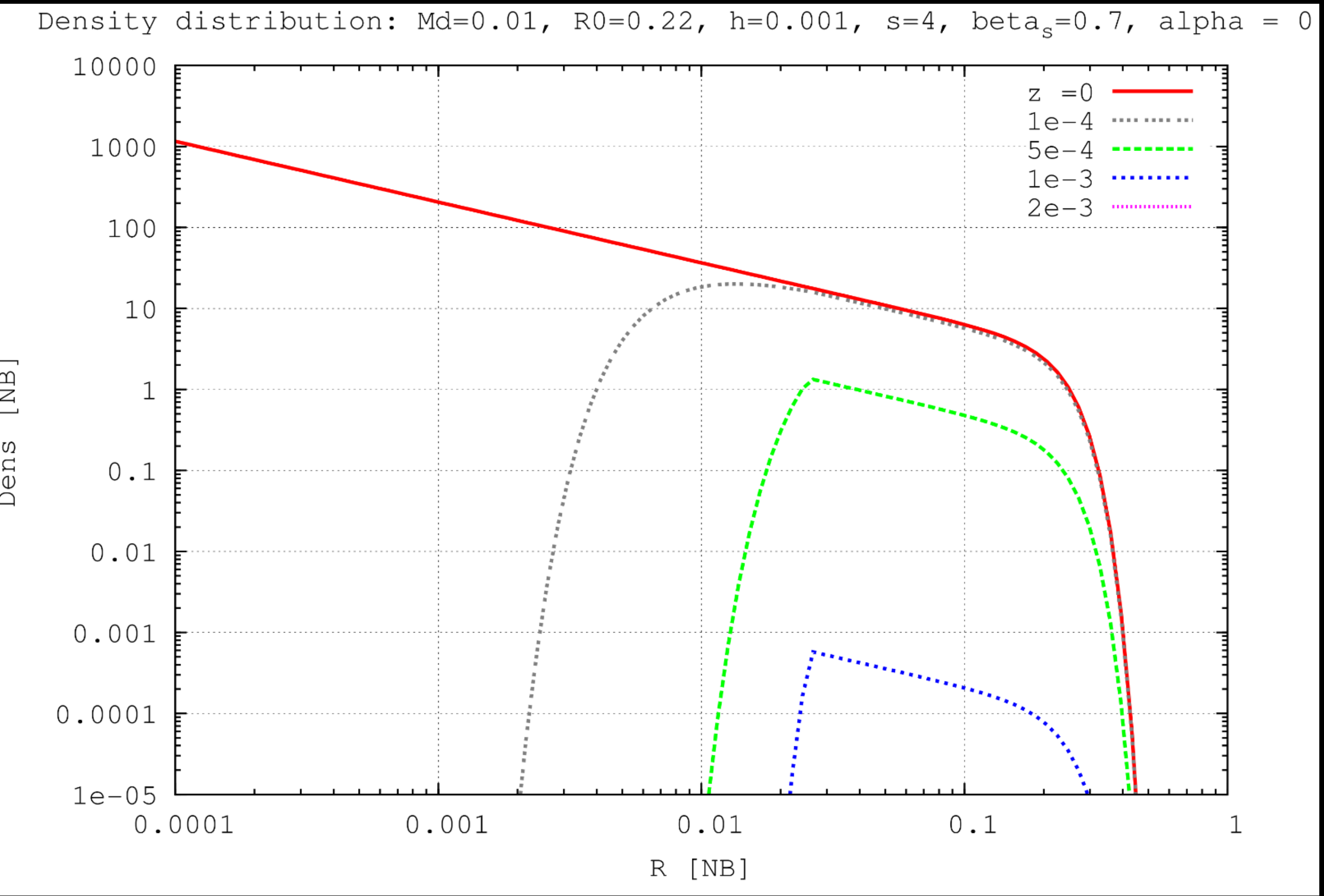
- Previous study used a constant disk height [3]
- We also use this disk model as to reproduce their results using a new approach
- Density profile in R, Z is: $\rho_{\rm g}(R,z) = \frac{\Sigma(R)}{\sqrt{2\pi}h_{\rm z}} \exp\left(-\frac{z^2}{2h_{\rm z}^2}\right)$





New Disk model

- We also use new disk model, which have variable height.



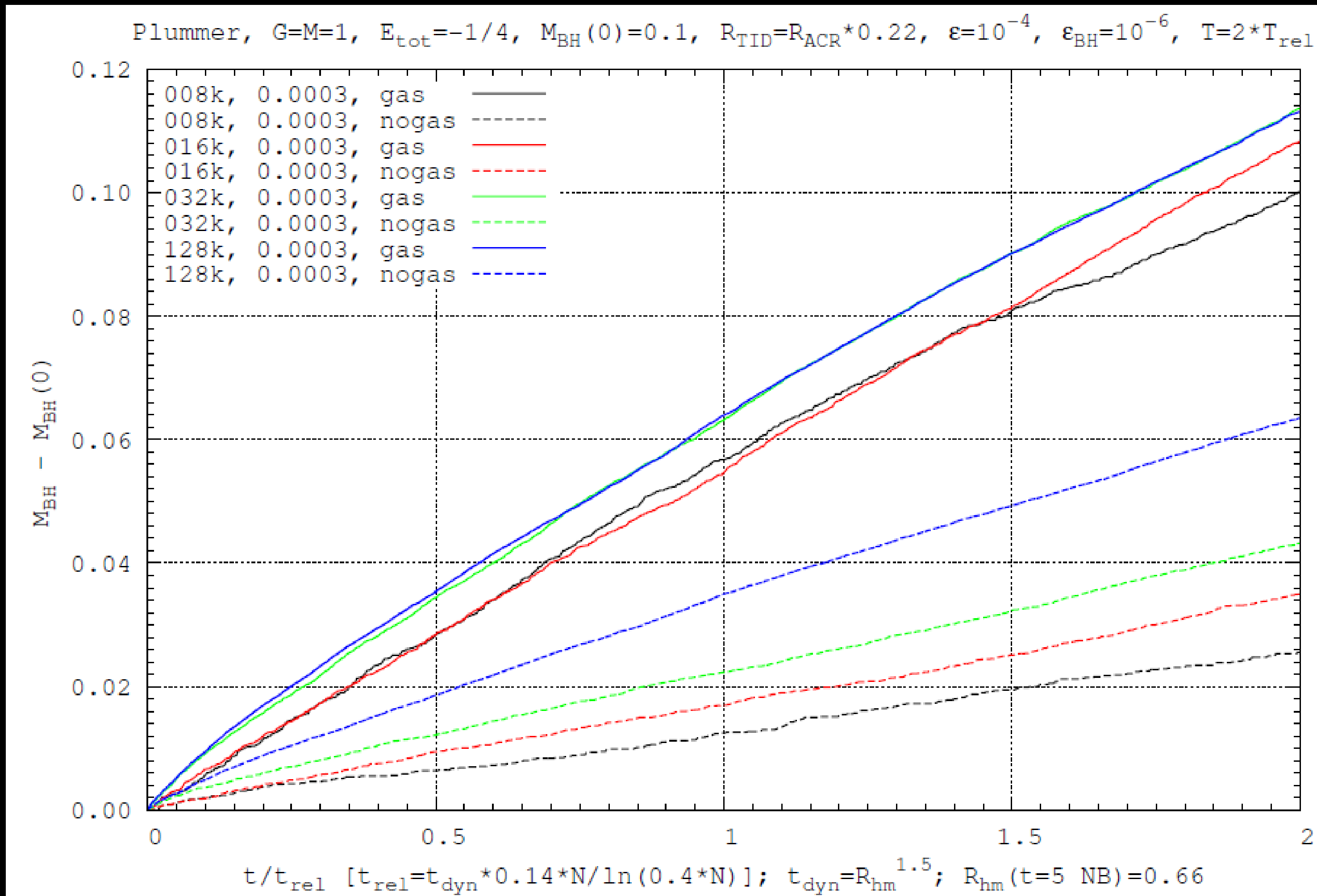
$$h_z = hR_0\left(\frac{R}{R_{crit}}\right)^{\zeta}$$

- $R_{crit} = 0.0257$

Simulation results

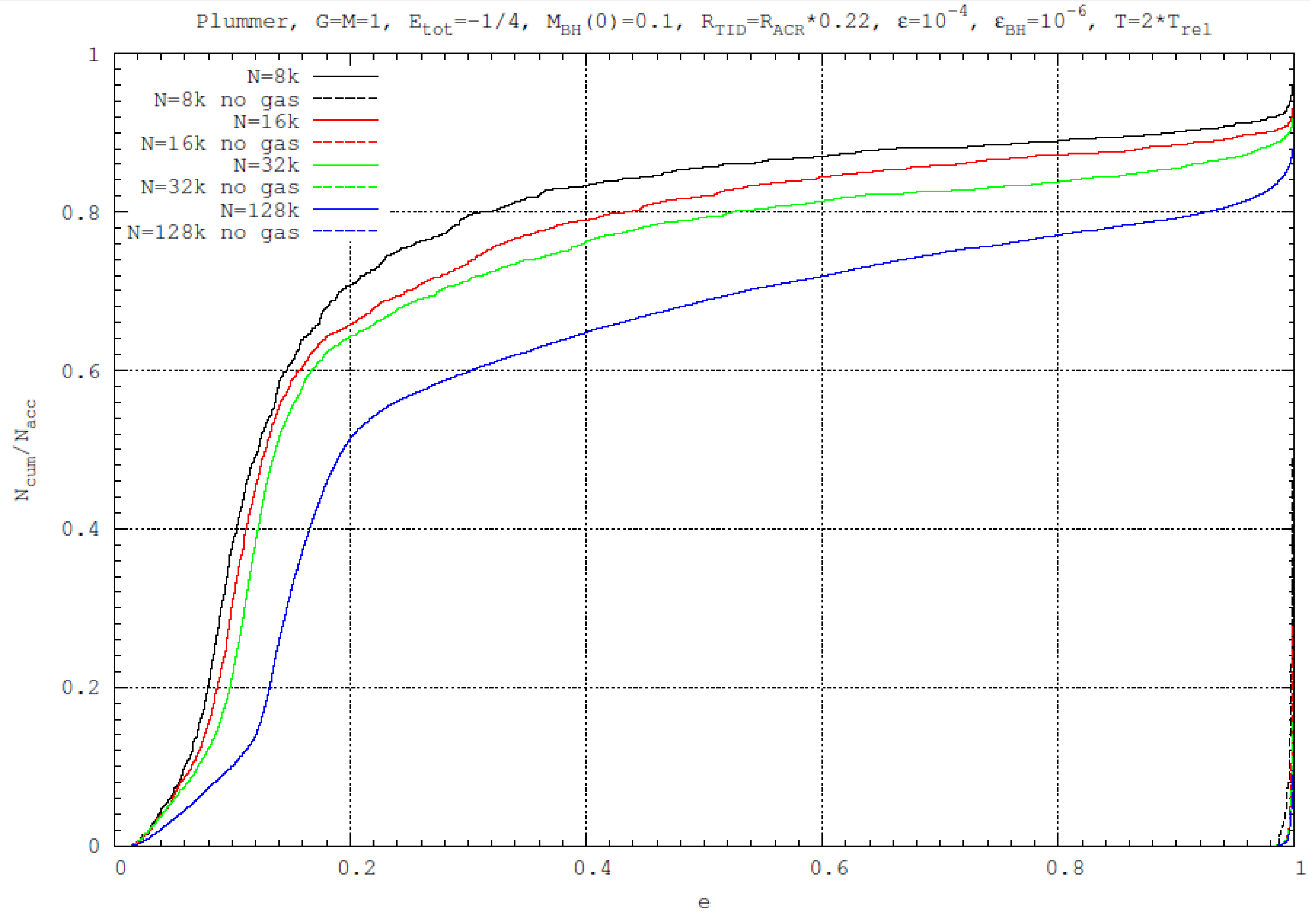
- These runs investigated the effect of particle number and accretion radius with and without gas, and the effect of two different gas disk model.
- Main results of interest are the mass growth of the MBH (originally M=0.1 in NBODY units) and the types of orbits stars (specifically their eccentricities) are on as they come into the accretion radius
- Particle numbers are: N = 8, 16, 32 and 128 k
- Accretion radius: R_{acc} = 0.0003, 0.0010, 0.0050 R_h
- Smallest accretion radius is still much more than R_S

Effect of different resolution: BH growth



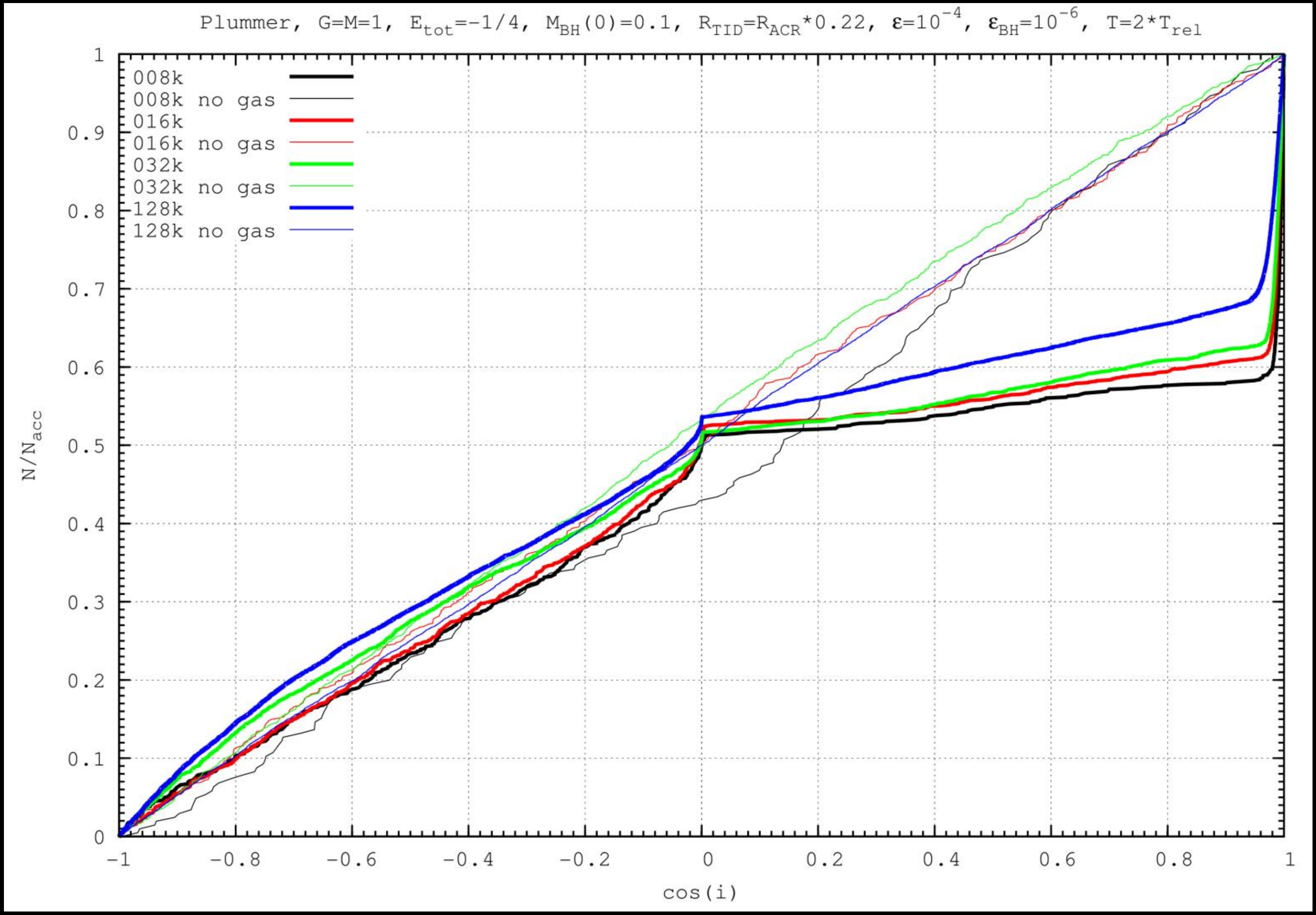
- Results are converging on the 128k run
- Gas models capture at a higher rate than models without gas

Effect of different resolution: eccentricity



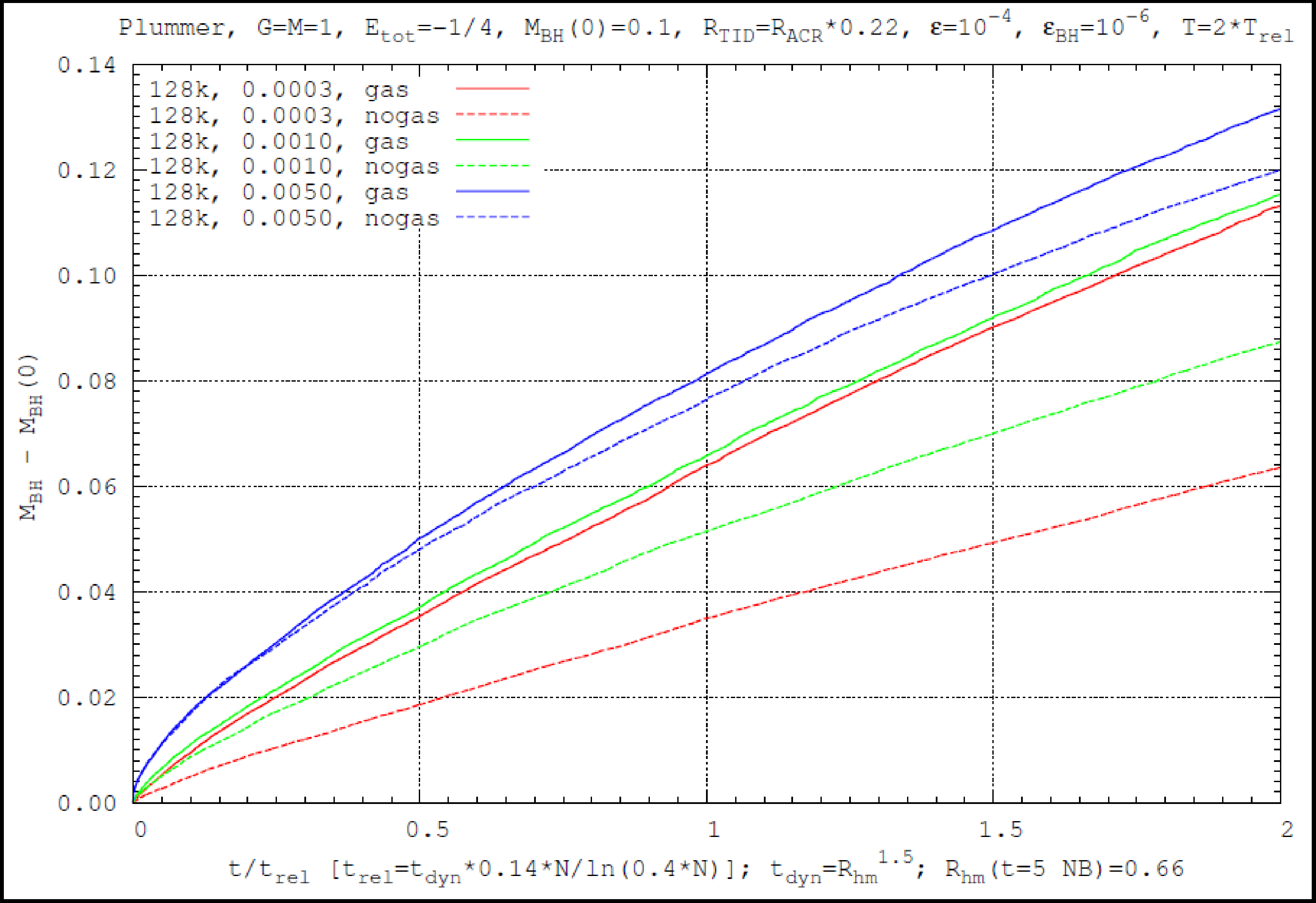
- 80 - 90% of stars fall inside R_{acc} on e < 0.8 orbits
- Most part of captured stars for gas models are on near circular orbits
- All captured stars for no gas models are on near radial (e=1) orbits

Effect of different resolution: inclination



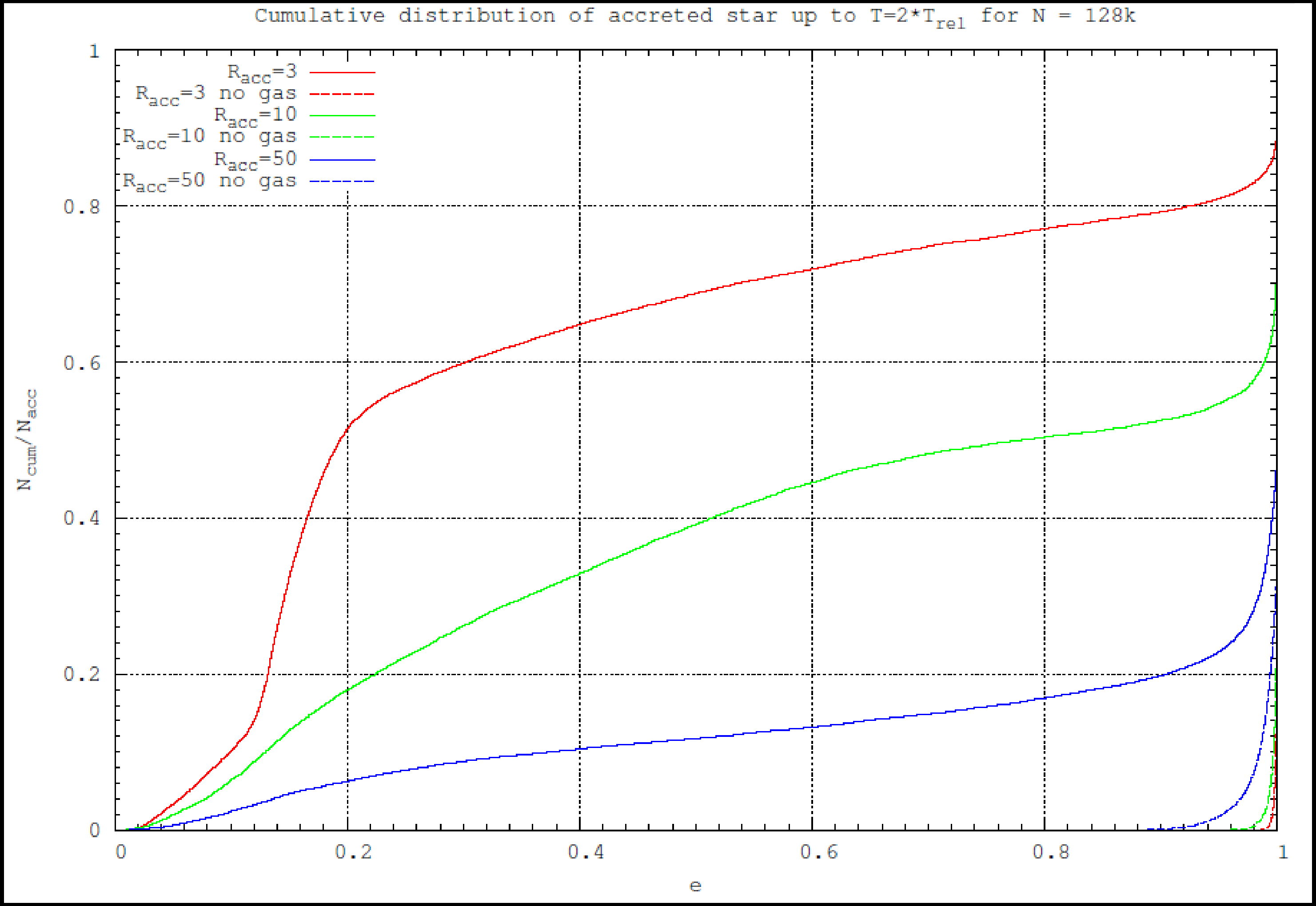
- Orbits of ~40% of accreted stars are in the gas disk

Effect of different R_{acc}: BH growth



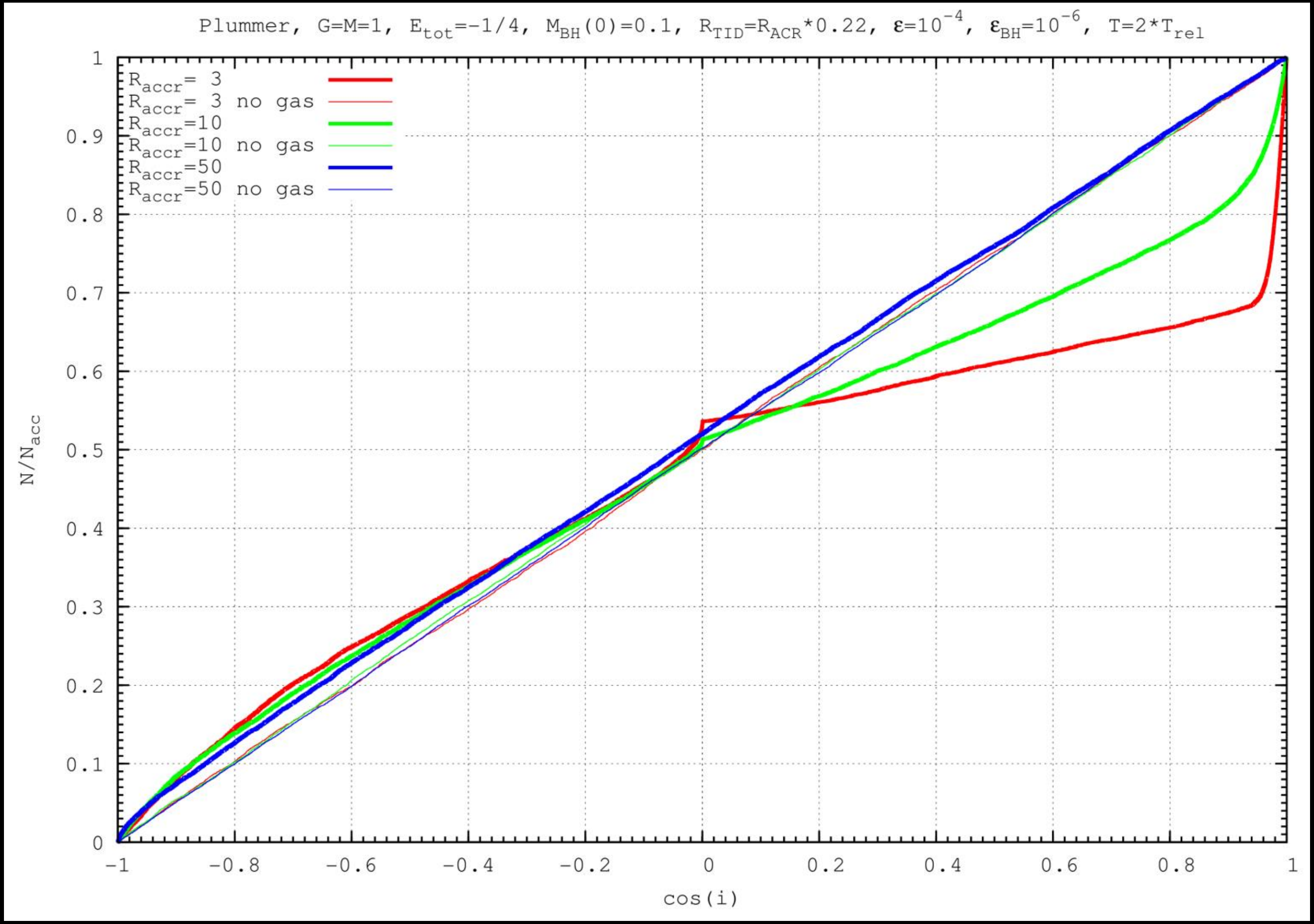
- Results are converging towards the R_{acc} = 0.0003 run

Effect of different R_{acc}: eccentricity

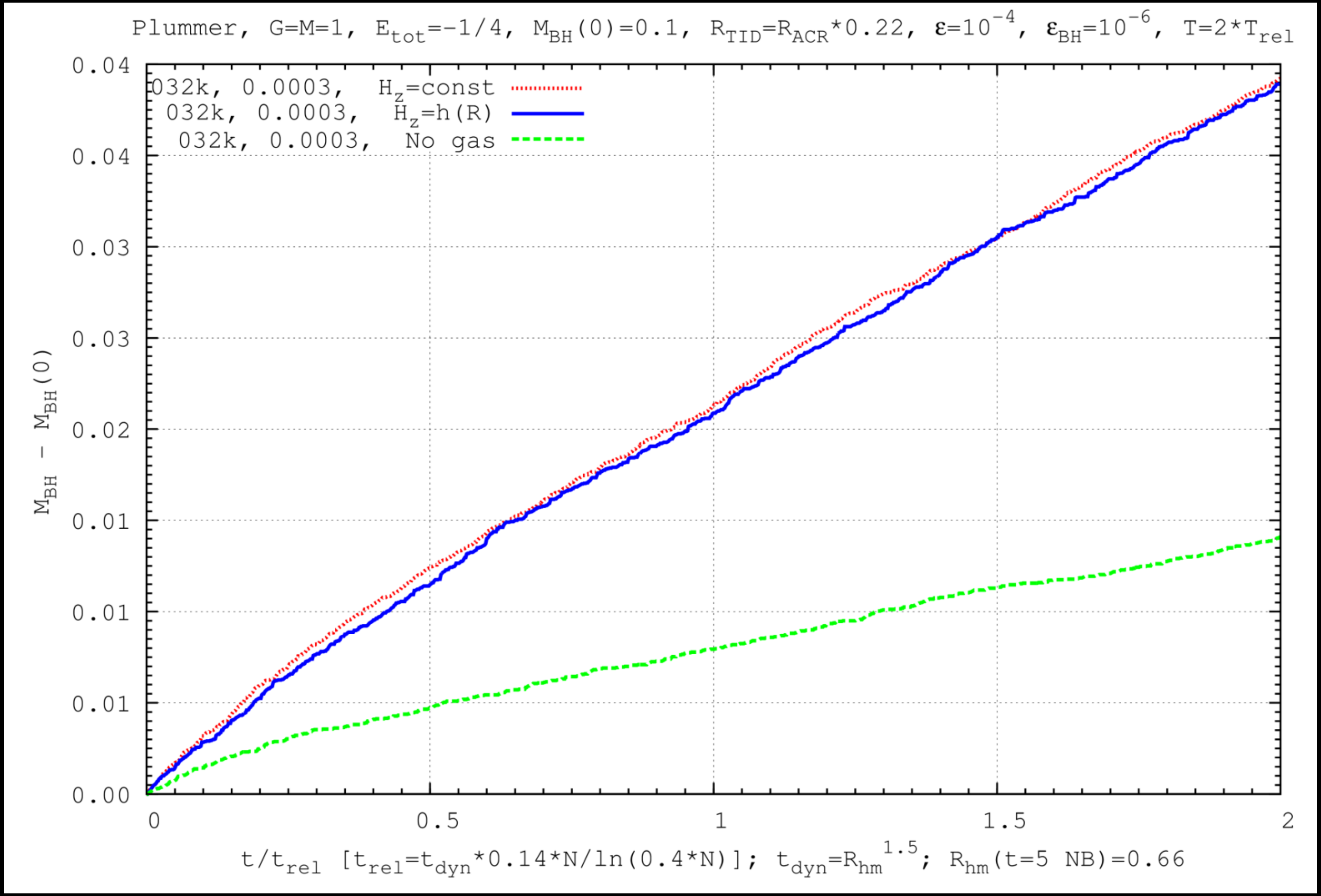


- Stars typically come into small R_{acc} only through the disk (e≈0)
- Captured on near radial orbits for larger R_{acc} due to larger target

Effect of different R_{acc}: inclination

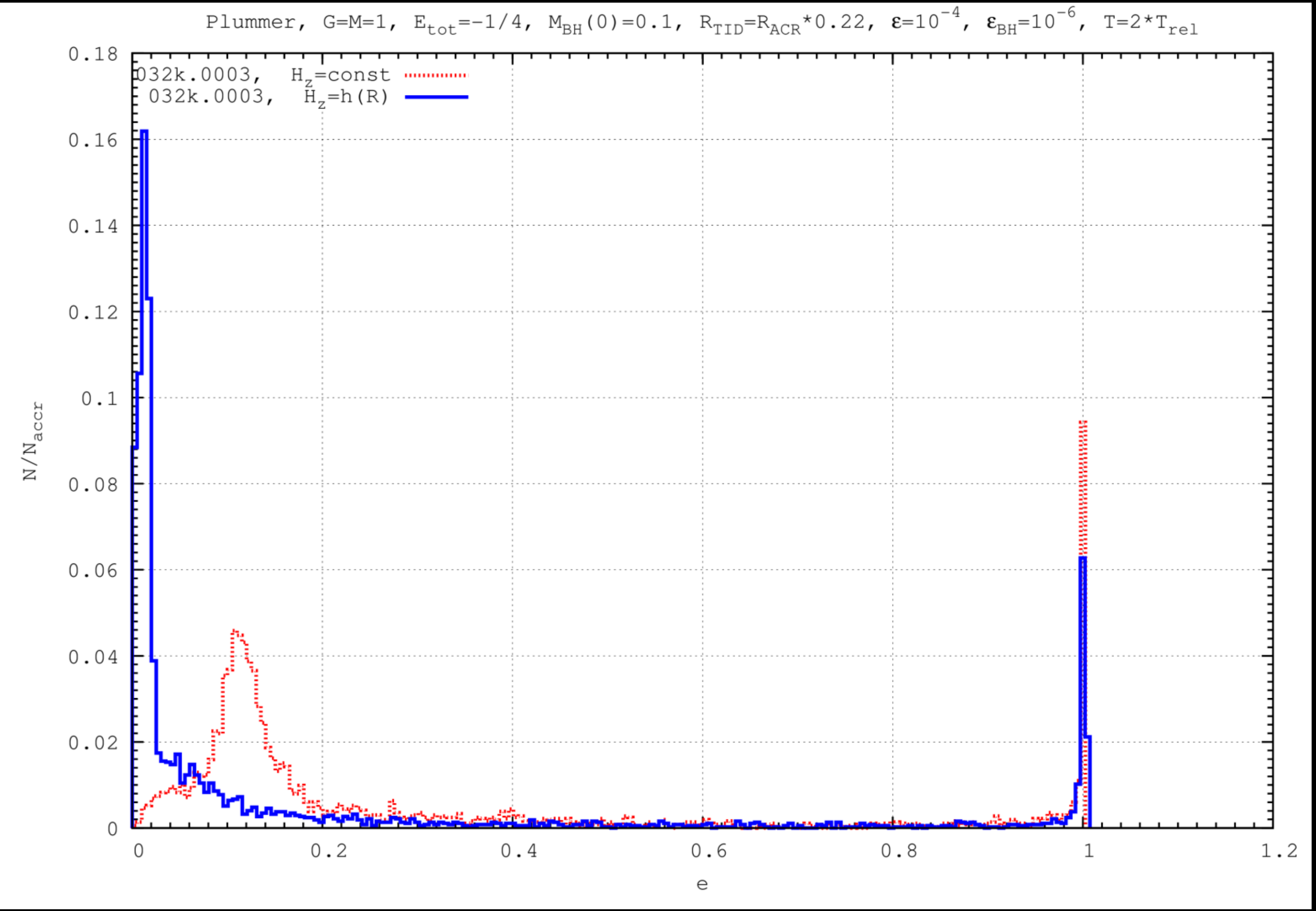


Effect of different disk models: BH growth



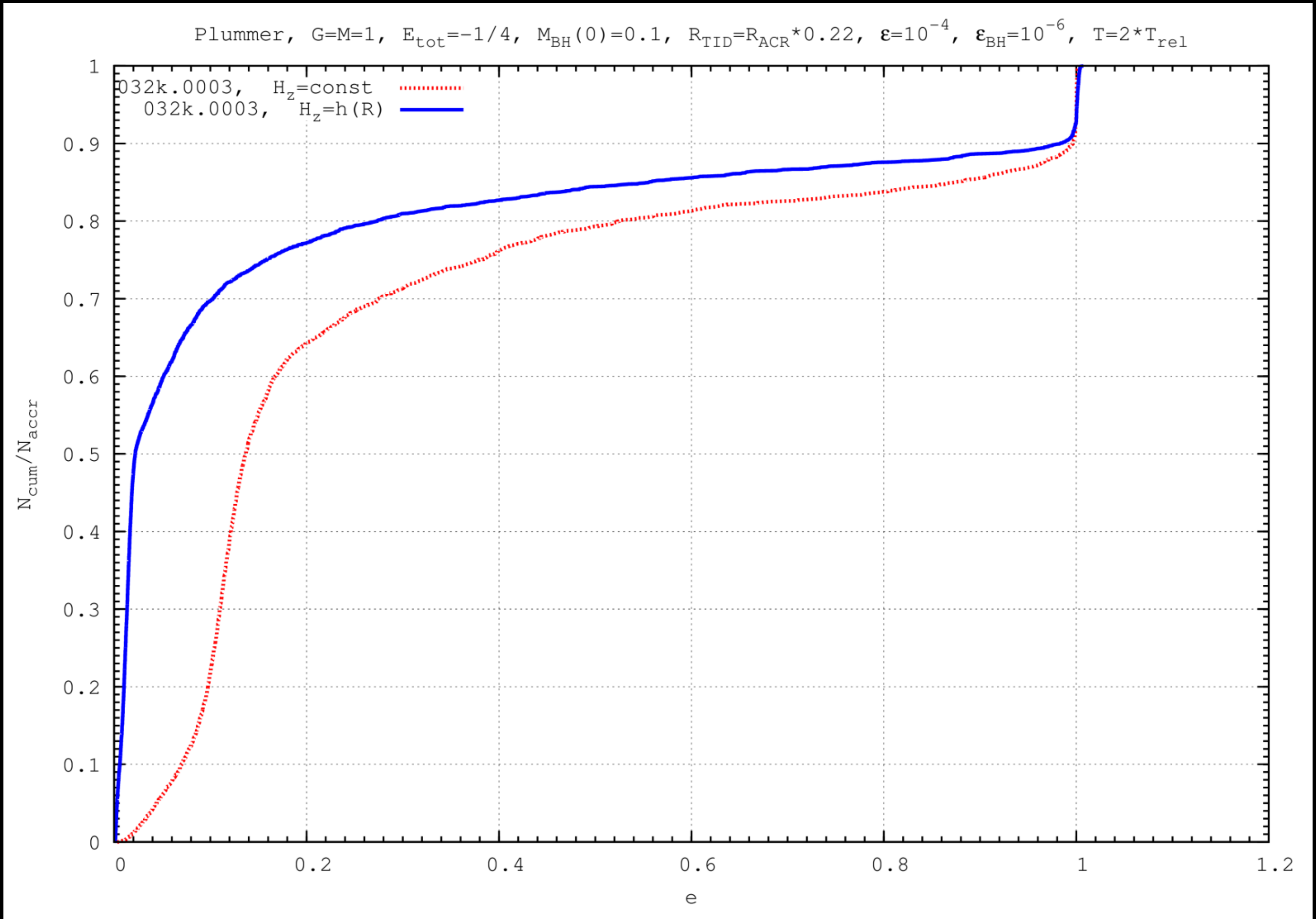
- Different gas disk models resulting same BH mass growth

Effect of different disk models: eccentricity



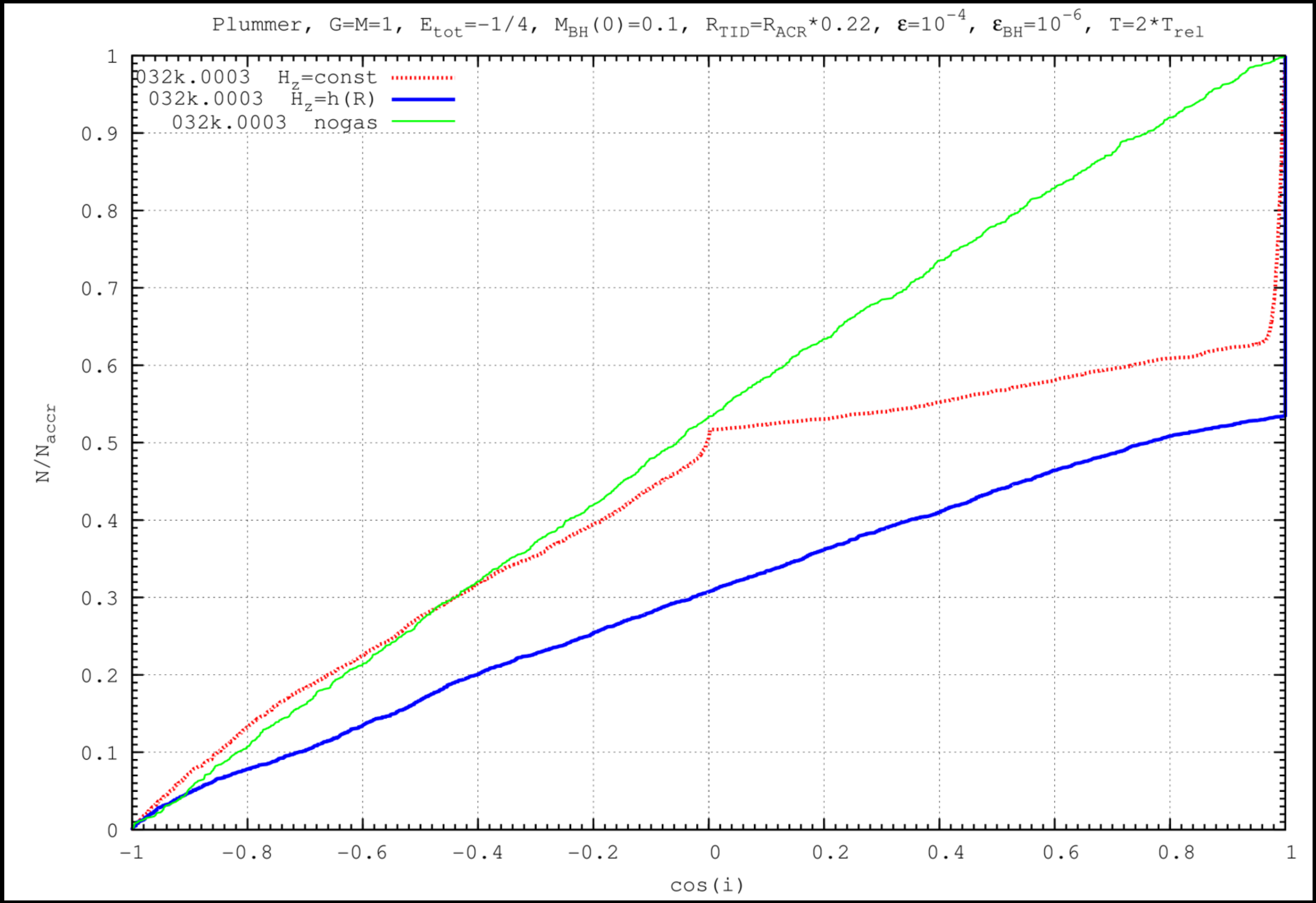
- New disk model gives big fraction of stars, which accreted in circular orbits ($e < 0.1$)

Effect of different disk models: eccentricity



- With new gas disk model ~ 75% of accreted particles have ($e < 0.2$) and ~ 50% have ($e < 0.05$)

Effect of different disk models: eccentricity



- With new gas disk model we have more particles accreted on the Disk plane

Conclusions

- Currently have a more realistic model of the accretion disk, including stellar dynamics and interactions, than any star-disk model to date
- Particle number of N = 32k is sufficient
- Accretion radius does not affect MBH growth once it is sufficiently small ($R_{acc} < 0.001\ R_{NB}$) consistent with Just et al 2012 [3]
- BUT it does affect the eccentricity distribution
- New gas disk model don't have difference on MBH growth
- But it have more effect on orbital distribution of accreted particles

THANK YOU!

References

1. Genzel, Ott, Eckart, Schödel and Alexander (2003) ApJ, **594**, 812
2. Gültekin et al. (2009) ApJ, **698**, 198
3. Just, Yurin, Makukov, Berczik, Omarov, Spurzem and Vilkoviskij (2012) ApJ, **758**, 51J