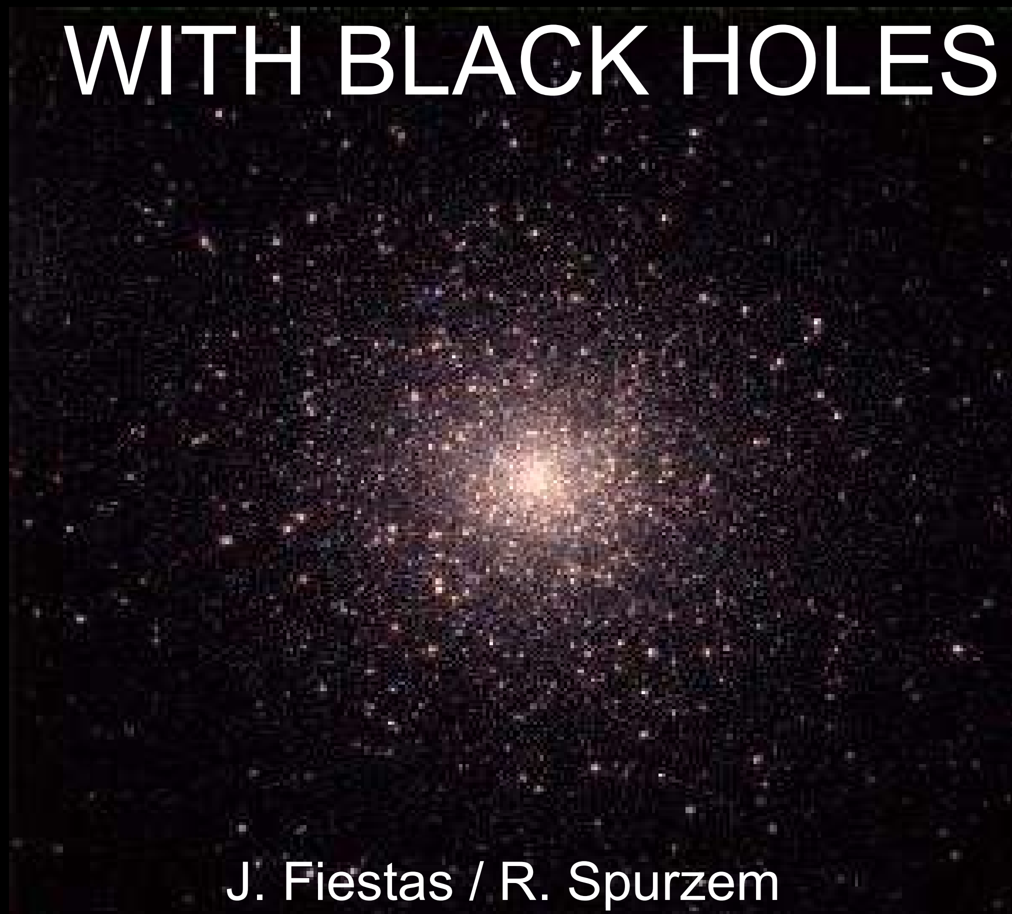
DYNAMICS OF ROTATING CLUSTERS WITH BLACK HOLES



J. Fiestas / R. Spurzem
Zentrum für Astronomie Heidelberg
Hoher List Meeting, 2006

Black Holes in Globular Clusters - Motivation

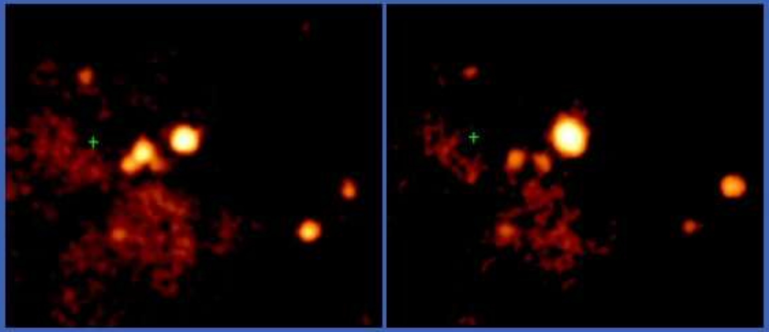
Black Holes in globular clusters:

Gebhardt et al. (2000), M15
Gerssen et al. (2002, 2003) , M15
Gebhardt et al. (2002), G1 (M31)

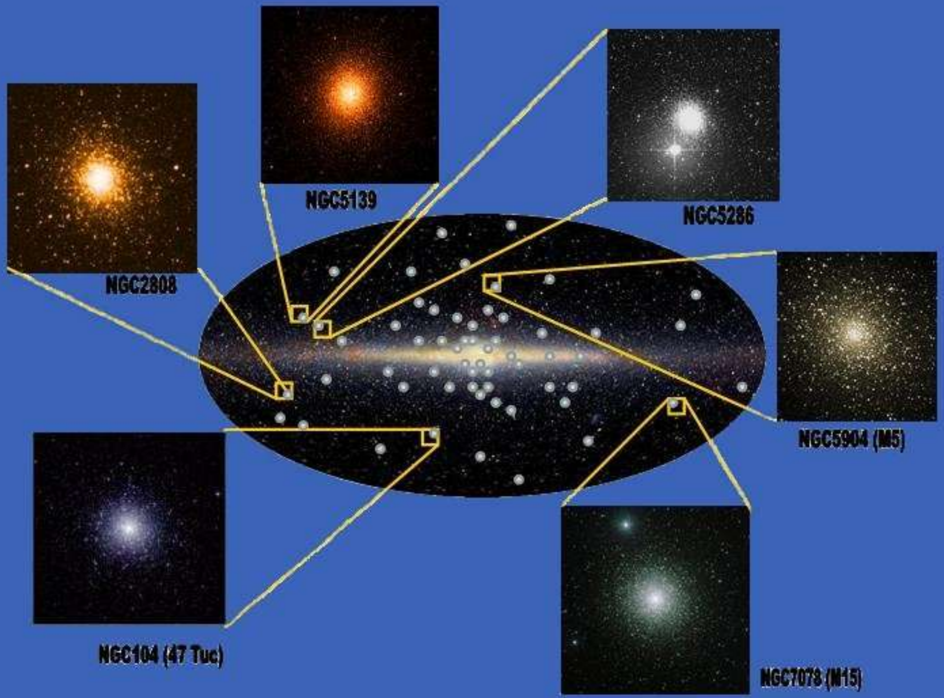
Rotation in globular clusters:

Meylan & Mayor (1986), ω Cen , 47 Tuc
Lupton, Gunn & Griffin (1987), M13
Van Leeuwen (2000), ω Cen
Anderson & King (2003), 47 Tuc
McLaughlin et al. (2005), 47 Tuc
van de Ven et al. (2006), ω Cen

NASA (AUR/STScI) and M. Rich (UCLA)



Chandra image of a dense cluster in M82



e=1 – b/a ~ 0.1 (MW GCs) to 0.2 (LMC GCs)

Black Holes in Globular Clusters - Motivation

Numerical models :

***Direct N-Body**: individual orbits of high N are integrated*

Spurzem & Aarseth (1996), Baumgardt & Makino (2003), Ardi et al. (2005)*, Baumgardt et al. (2004)

***Monte Carlo**: diffusion of (random generated) velocities are calculated at selected test particles*

Marchant & Shapiro (1980) , Spurzem & Giersz (1996), Giersz & Spurzem (2003)

***Fokker Planck**: Boltzmann equation + collisional term*

Lightman & Shapiro (1977), Takahashi (1995,1996,1997), Einsel & Spurzem (1999)*, Kim et al. (2002, 2004)*

***Gaseous Model:** Momentum of the Fokker Planck equation*

Louis & Spurzem (1991), Amaro-Seoane et al. (2004)

(* rotation)

‚Seed' BHs in GCs:

Portegies Zwart et al. (2002)
Baumgardt et al. (2005)
Freitag et al. (2005)

Aims:

- Implications in evolution of rotation in relaxed systems with BH

- Link between stellar-mass and supermassive BHs

Black Holes in Globular Clusters - Model

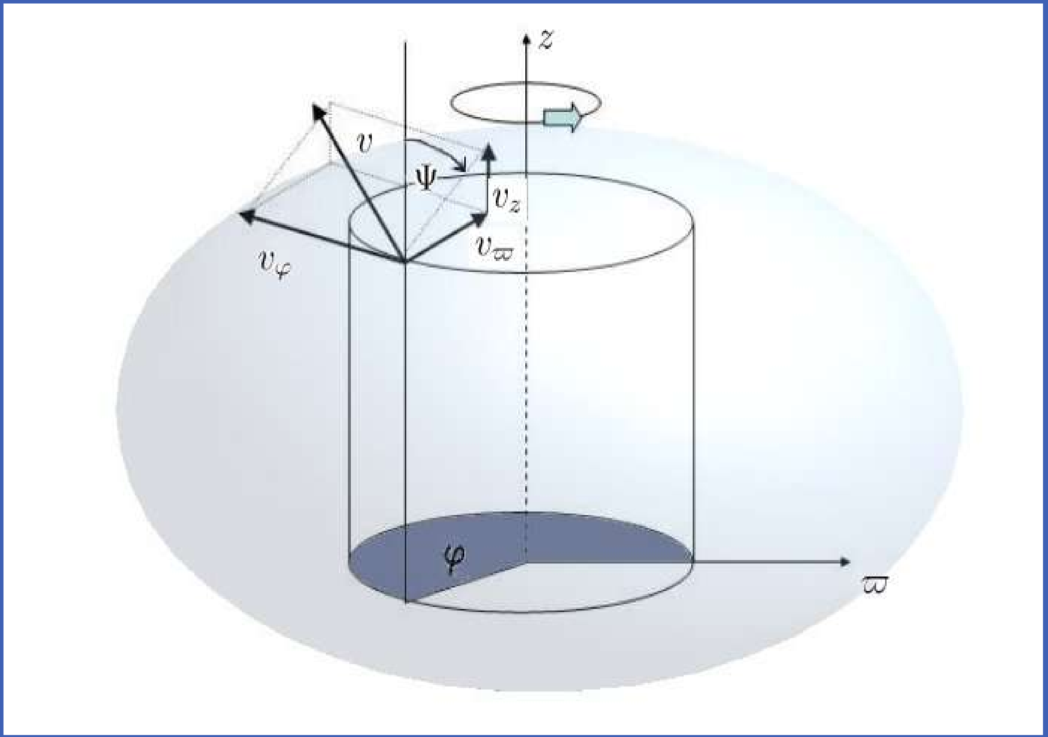
Fokker Planck model

***Initial conditions*:**

- *single-mass system axisymmetric in space, anisotropic in velocity space*
- *cluster evolution time scales:*

$$\tau_{\rm cl} > \tau_{\rm rh} \gg \tau_{\rm dyn}$$

$$\tau_{\rm rh} = \frac{0.138\sqrt{N r_{\rm h}^3}}{\sqrt{Gm}\; ln\Delta}$$



- *Changes in f(x,v) due to small angle scatterings*

$$\vec{v} \;\; \text{to} \;\; \vec{v} + \Delta\vec{v}$$

$$\Delta v / v \ll 1$$

- *$M_* < M_{bh} << M_{cl}$*

- *Tidal galaxy boundary*

$$\frac{r_{\rm tid}(t)^3}{r_{\rm G}^3} = \frac{M_{\rm cl}(t)}{M_{\rm G}}$$

- *stars are **possibly** disrupted if* $J_z < J_z^{\,min}$*, leading to BH growing*

Black Holes in Globular Clusters - Model

***Rotating King models*:**

$$f(E, J_z) \propto \exp\left(-\beta\Omega_0 J_z\right) \cdot \left[\exp\left(-\beta E\right) - 1\right]$$

$$W_0 = -\beta(\phi_c - \phi_t) \quad (3, 6, 9)$$

$$\omega_0 = \sqrt{9/(4\pi G n_c)}\Omega_0 \quad (0.0, 0.3, 0.6, 0.9, 1.2)$$

$$E = \frac{1}{2}v^2 + \phi_{cl}(\varpi, z) + \phi_{bh}(\varpi, z)$$

$$J_z = \varpi \vec{v} \hat{e}_\varphi$$

Model name	W_0	ω_0
A1	3.0	0.00
A2	3.0	0.30
A3	3.0	0.60
A4	3.0	0.90
A5	3.0	1.20
B1	6.0	0.00
B2	6.0	0.30
B3	6.0	0.60
B4	6.0	0.90
B5	6.0	1.20
C1	9.0	0.20
C2	9.0	0.30
C3	9.0	0.40
C4	9.0	0.50

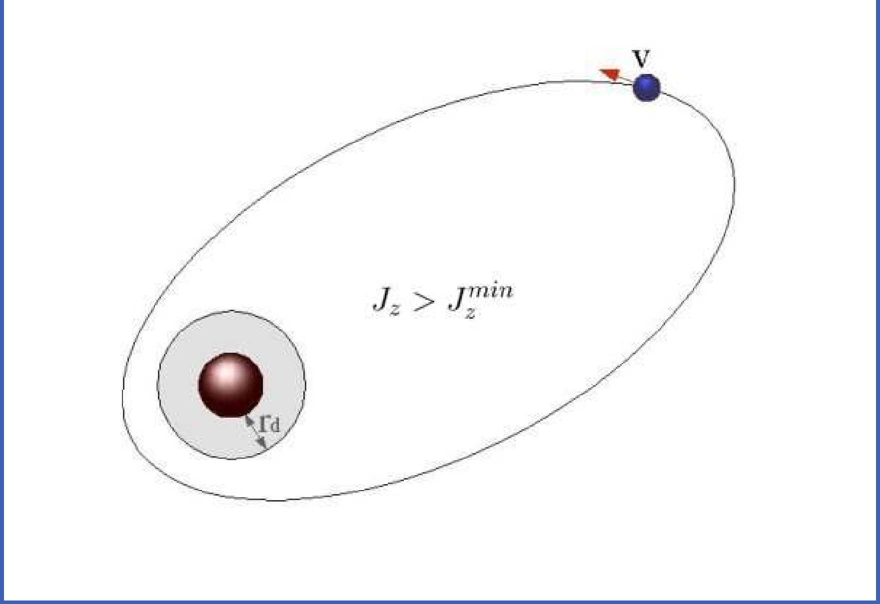
Black Holes in Globular Clusters - Model

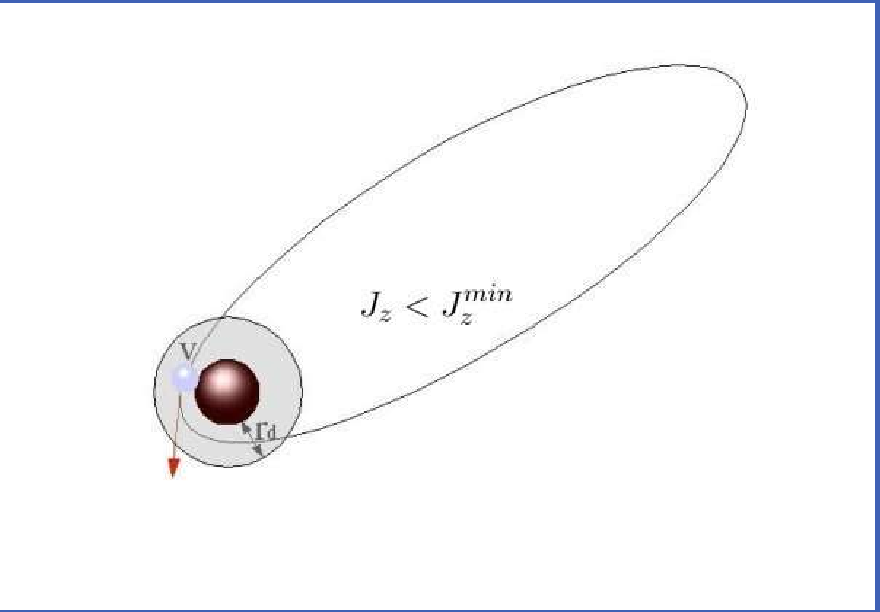
Star accretion:

$$r_{\rm d} \sim r_*(M_{\rm bh}/m_*)^{1/3}$$

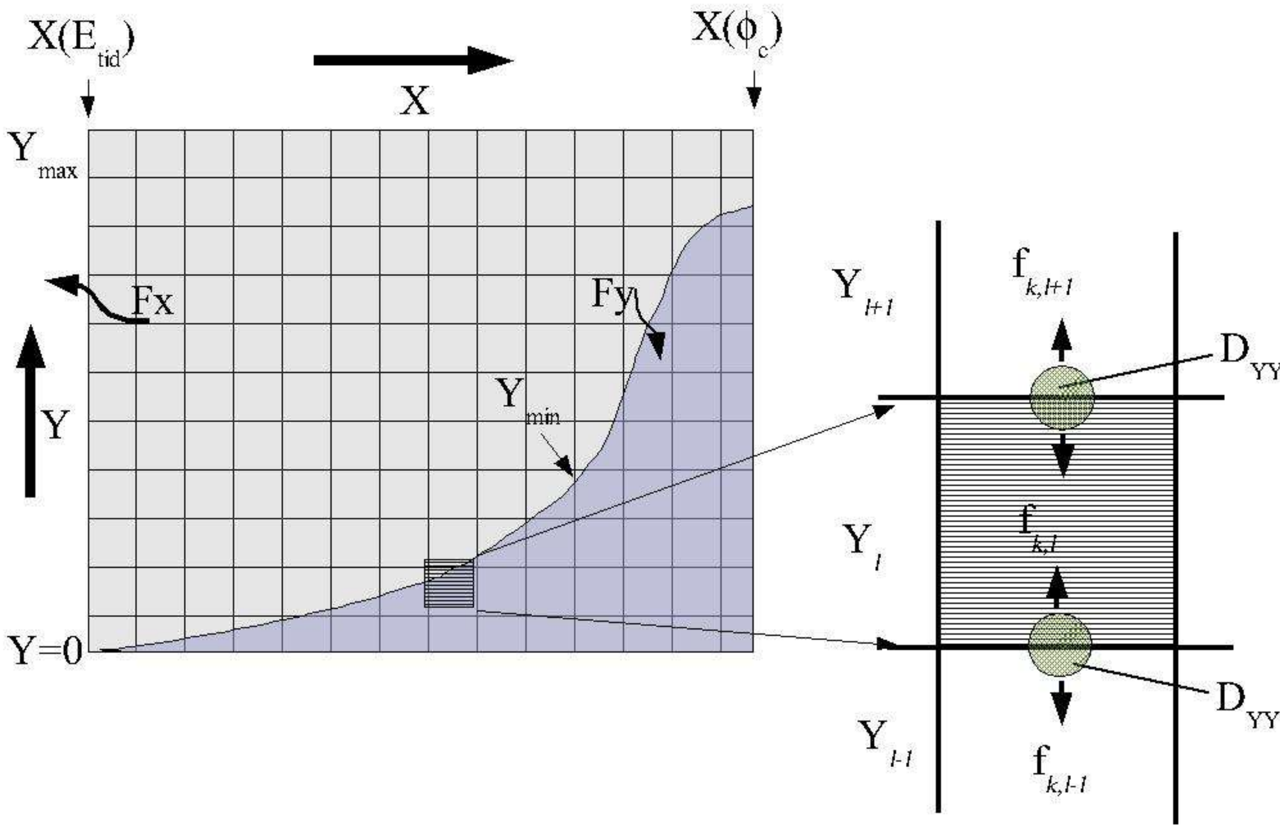
$$J_z^{min}(E) = r_d\sqrt{2(E - GM_{\rm bh}/r_d)}$$

Are all stars in orbits of $J_z < J_{z,min}$ disrupted?





Black Holes in Globular Clusters - Model



Loss cone:

$$J_z < J_z^{min}$$

$$X(E) \equiv \ln\left(\frac{E}{2\phi_c - E_0 - E}\right)$$

$$Y(J_z, E) \equiv \frac{J_z}{J_z^{max}}$$

$$\frac{df}{dt} = \frac{1}{p}\left(-\frac{\partial F_E}{\partial E} - \frac{\partial F_{J_z}}{\partial J_z}\right)$$

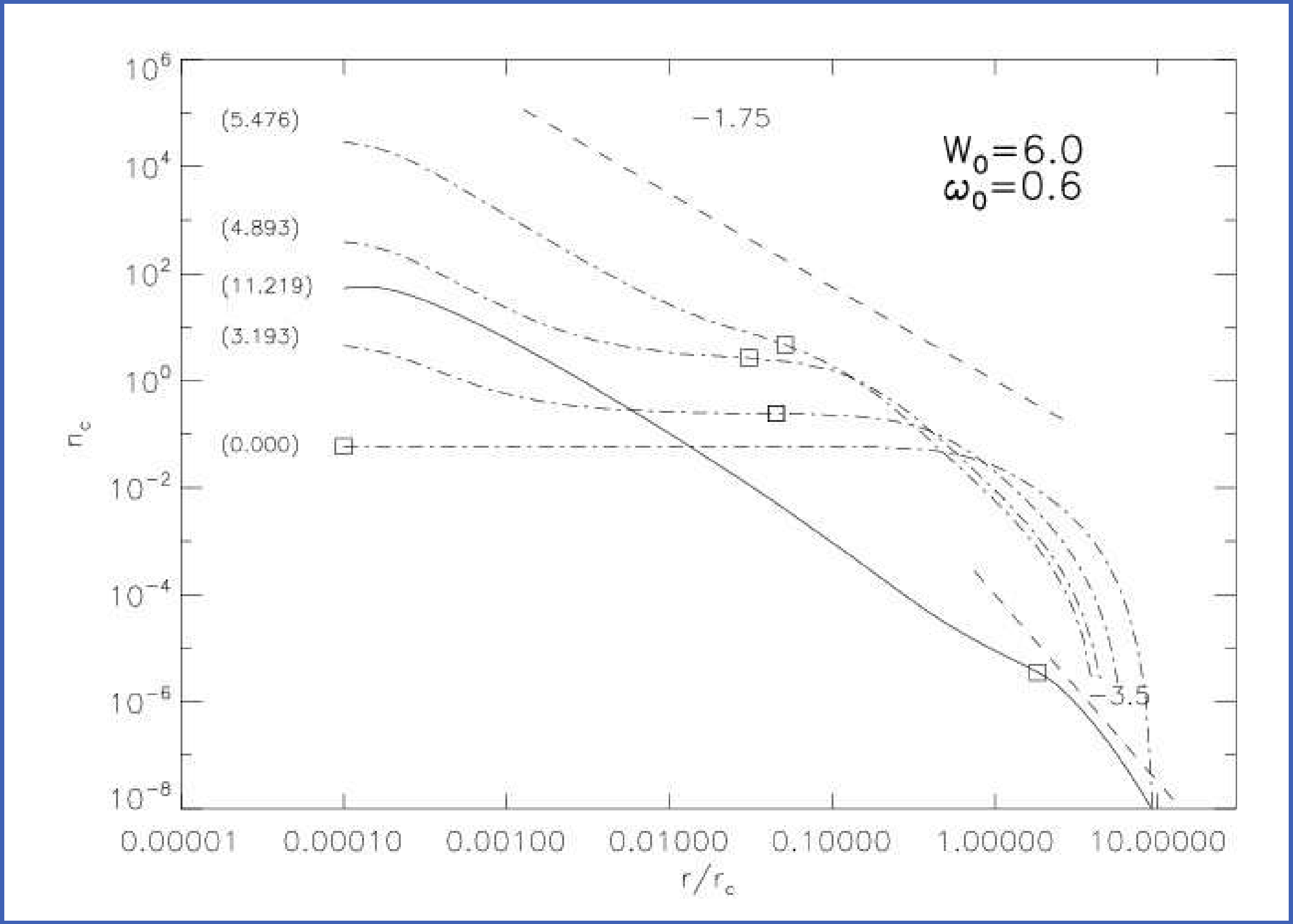
$$F_E = -D_{EE}\frac{\partial f}{\partial E} - D_{EJ_z}\frac{\partial f}{\partial J_z} - D_E f;$$

$$F_{J_z} = -D_{J_z J_z}\frac{\partial f}{\partial J_z} - D_{J_z E}\frac{\partial f}{\partial E} - D_{J_z} f$$

Black Holes in Globular Clusters - Results

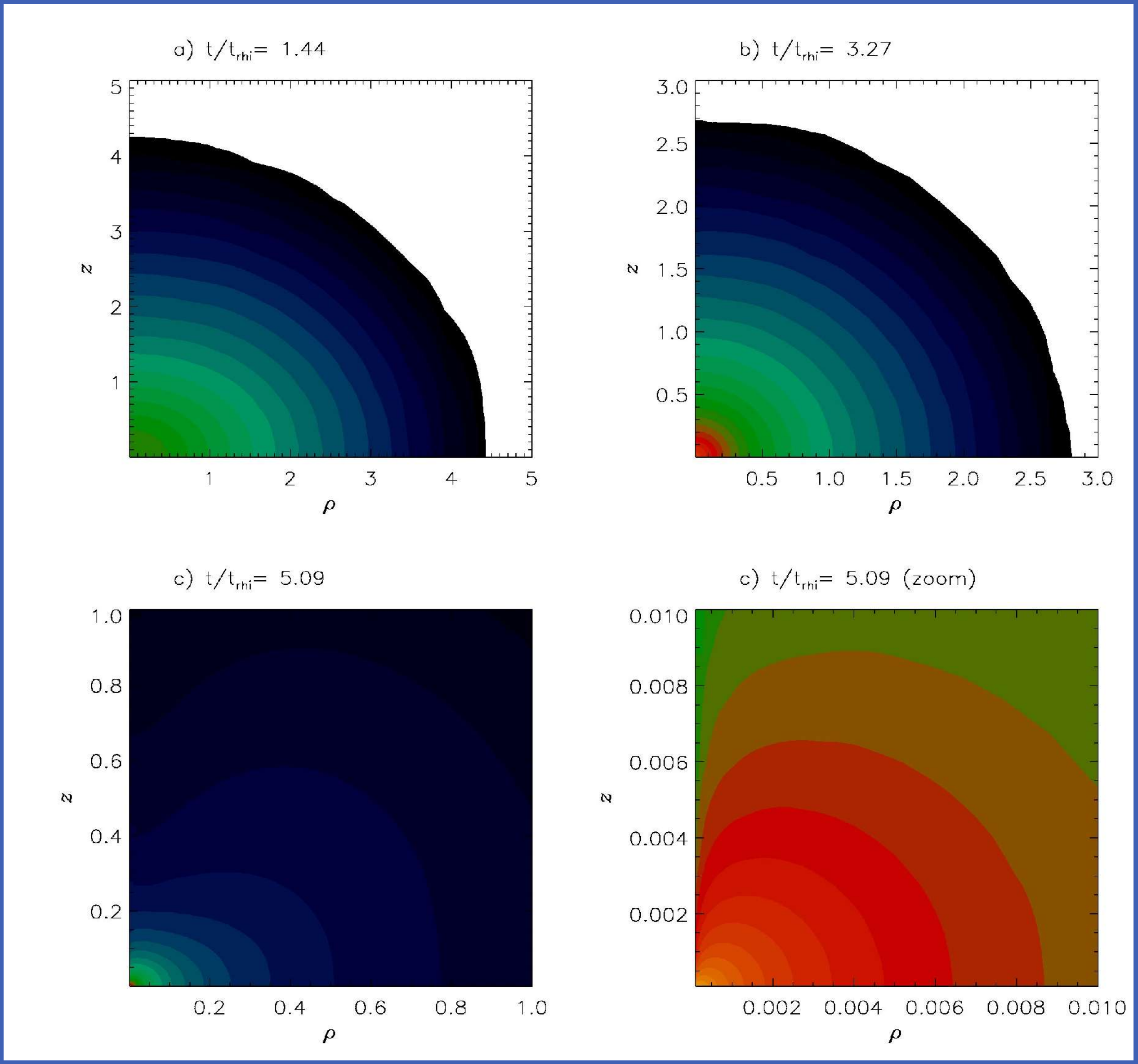
Evolution of density profile:

-7/4 cusp (Bahcall & Wolf 1976, Lightman & Shapiro 1977) forms inside influence radius (squares)



Black Holes in Globular Clusters - Results

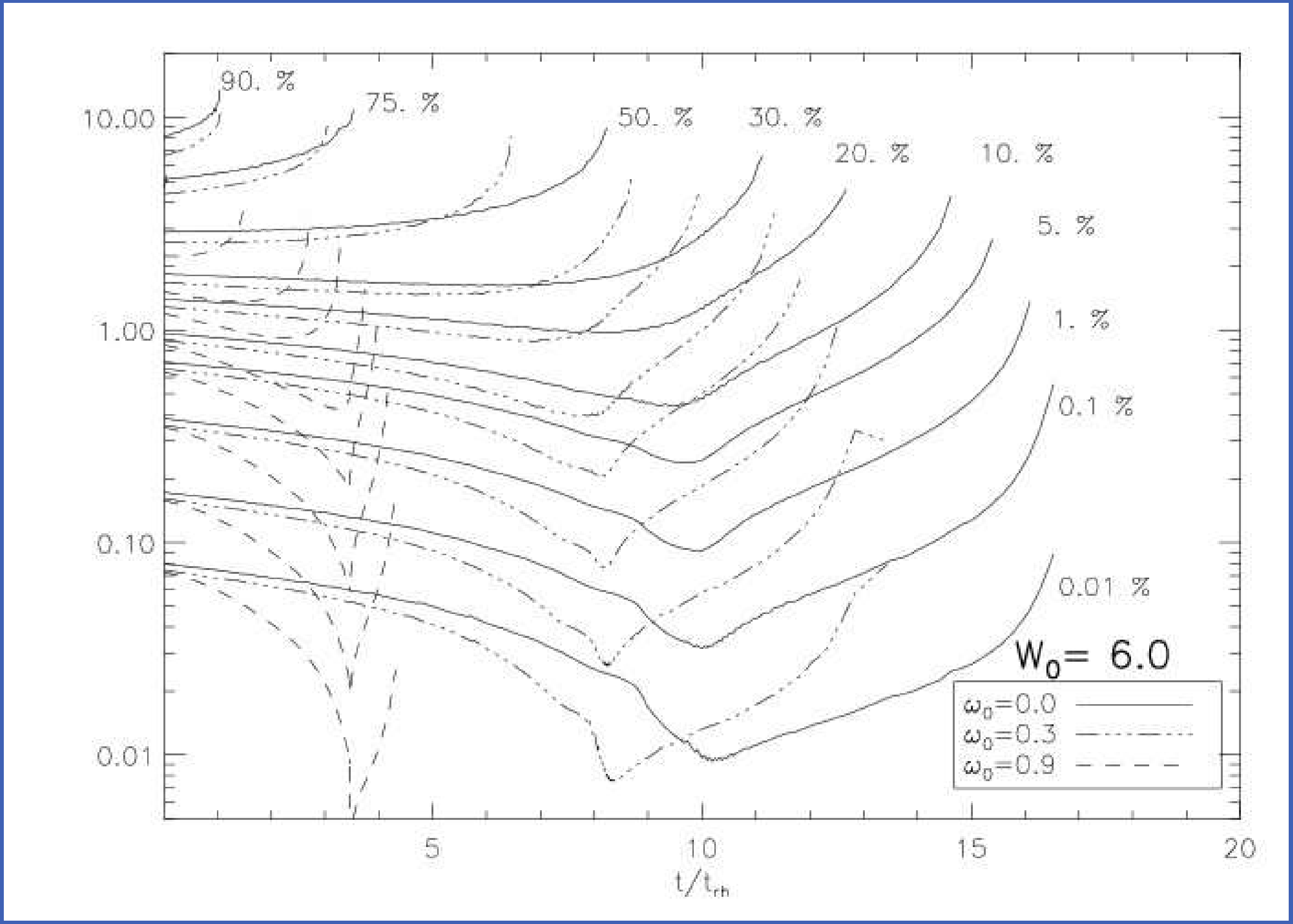
2D evolution of density:
Effects of rotation



Black Holes in Globular Clusters - Results

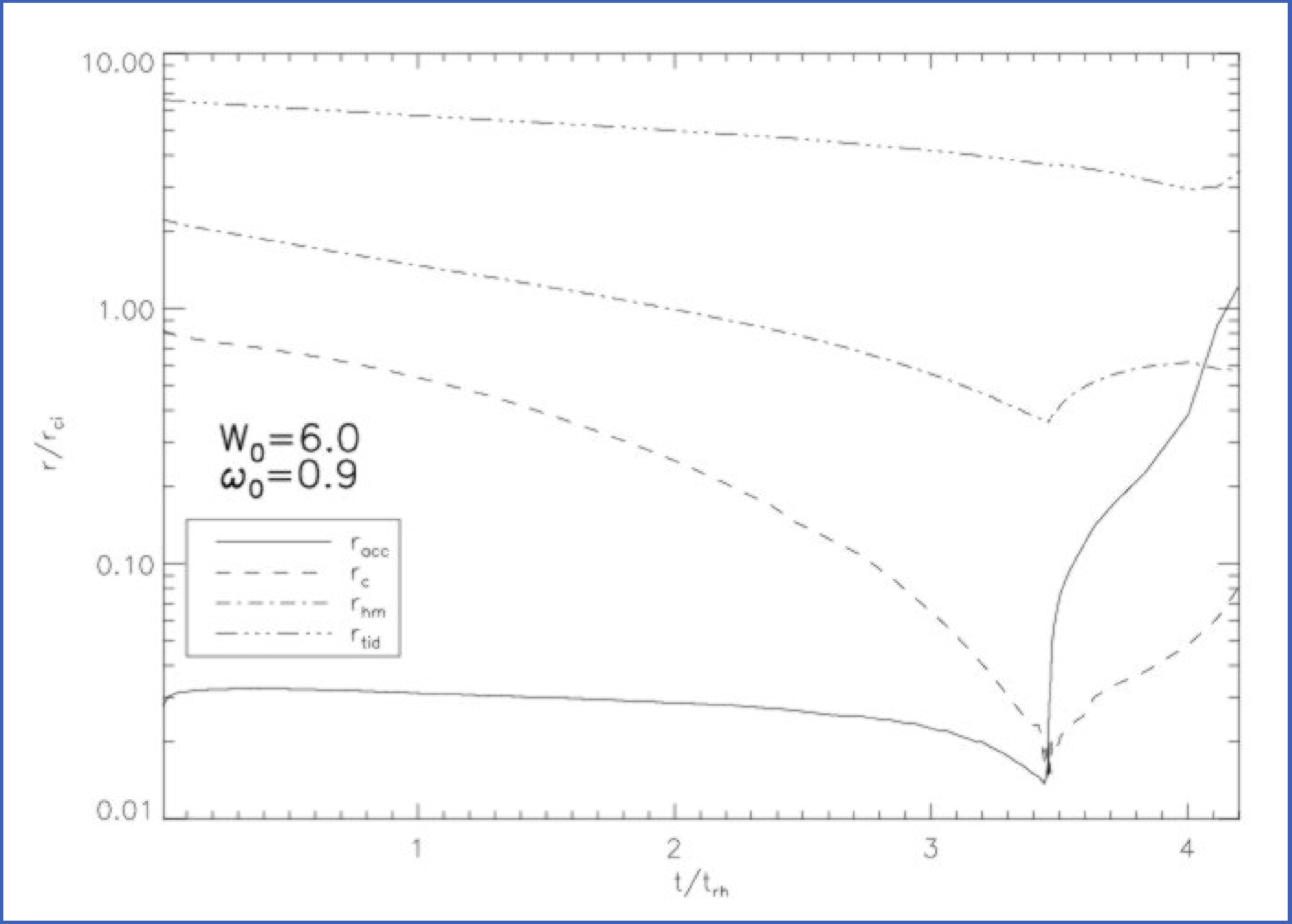
Evolution of Lagrange Radii *(dependence on initial rotation ω_0):*

Outer mass shells are faster depleted



Black Holes in Globular Clusters - Results

Evolution of cluster Radii:
Core radius (r_c) falls up to collapse, Influence Radius (r_a) larger after collapse,



Black Holes in Globular Clusters - Results

Evolution of cluster masses: M_{bh} stalls (dM_{bh}/dt has a maximum) at collapse.
$M_{bh} \sim 0.01\ M_{cl.}$ M_{cl} drops faster in BH-model

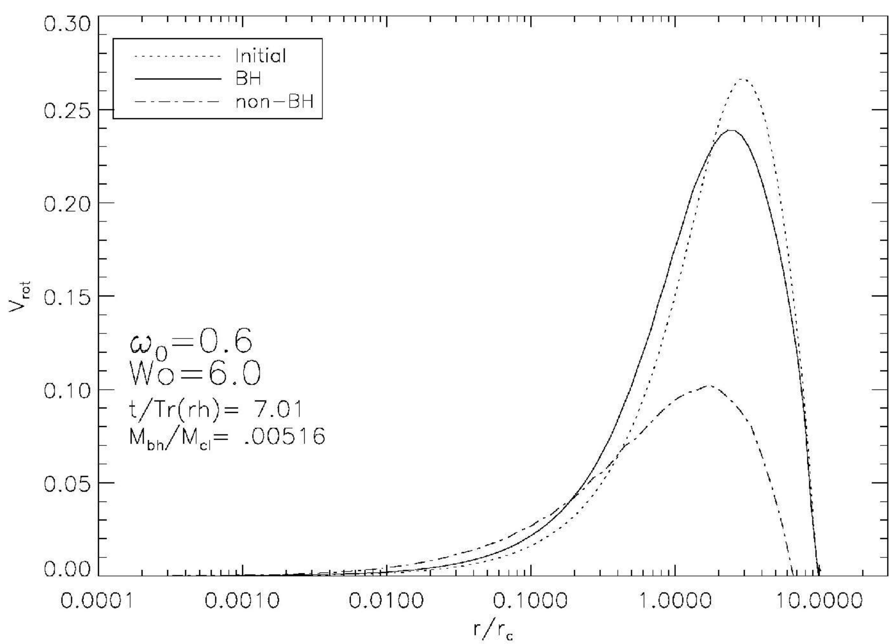
Model name	$M_{\rm BH}^{\rm stall}$ $(M_\odot)$	$dM/dt_{\max}$ $(M_\odot/{\rm yr})$
A1	$2.1 \cdot 10^4$	$1.77 \cdot 10^{-3}$
A2	$2.7 \cdot 10^4$	$1.32 \cdot 10^{-3}$
A3	$3.0 \cdot 10^3$	$1.21 \cdot 10^{-3}$
A4	$4.4 \cdot 10^3$	$2.83 \cdot 10^{-4}$
A5	$5.0 \cdot 10^3$	$3.24 \cdot 10^{-3}$
B1	$4.8 \cdot 10^4$	$3.40 \cdot 10^{-4}$
B2	$4.2 \cdot 10^4$	$4.74 \cdot 10^{-4}$
B3	$8.5 \cdot 10^4$	$1.39 \cdot 10^{-3}$
B4	$9.5 \cdot 10^4$	$3.78 \cdot 10^{-3}$
B5	$4.5 \cdot 10^4$	$1.30 \cdot 10^{-2}$
C1	$5.0 \cdot 10^3$	$5.38 \cdot 10^{-4}$
C2	$2.3 \cdot 10^3$	$1.87 \cdot 10^{-5}$
C3	$1.5 \cdot 10^3$	$4.29 \cdot 10^{-6}$
C4	$1.9 \cdot 10^3$	$4.76 \cdot 10^{-6}$

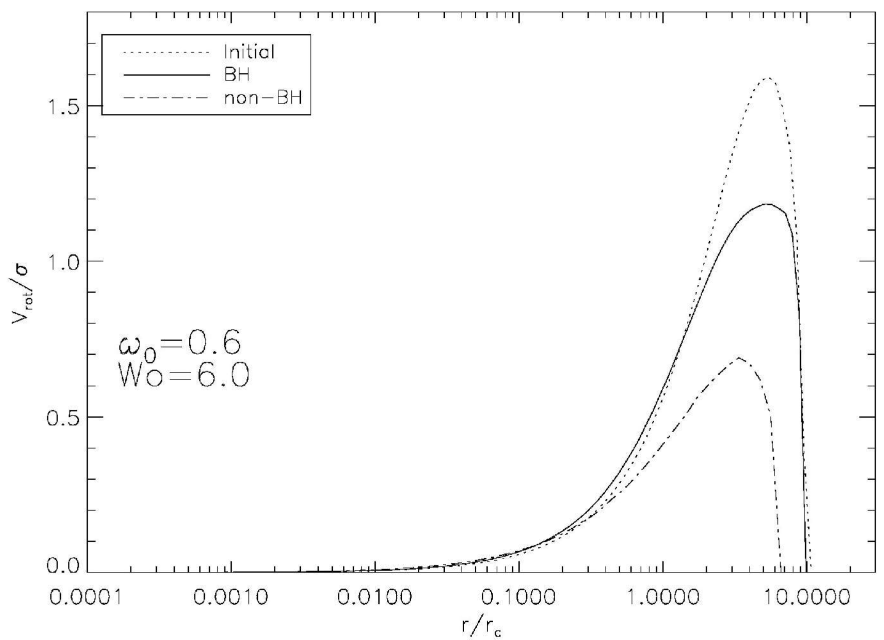
Black Holes in Globular Clusters - Results

Evolution of rotational velocity *:*
Gravogyro instabilities carry out angular momentum and core rotates faster. BH supports rotation

$$\delta\Omega \approx -\frac{\delta j}{r^2}$$

Inagaki & Hachisu (1978)



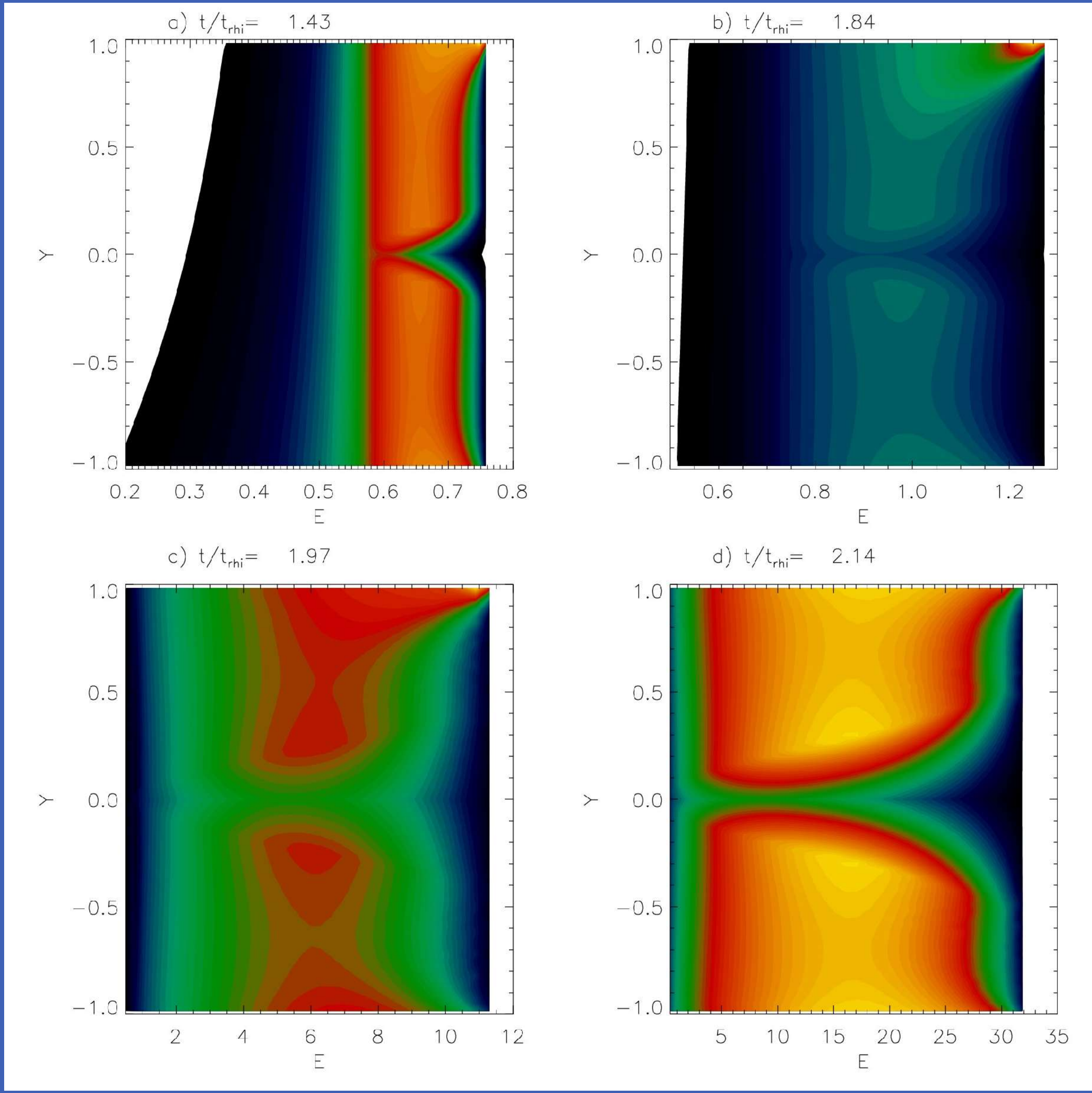


Black Holes in Globular Clusters - Results

Distribution function f(E,Jz)

(-1 ≤ Y ≤ +1)

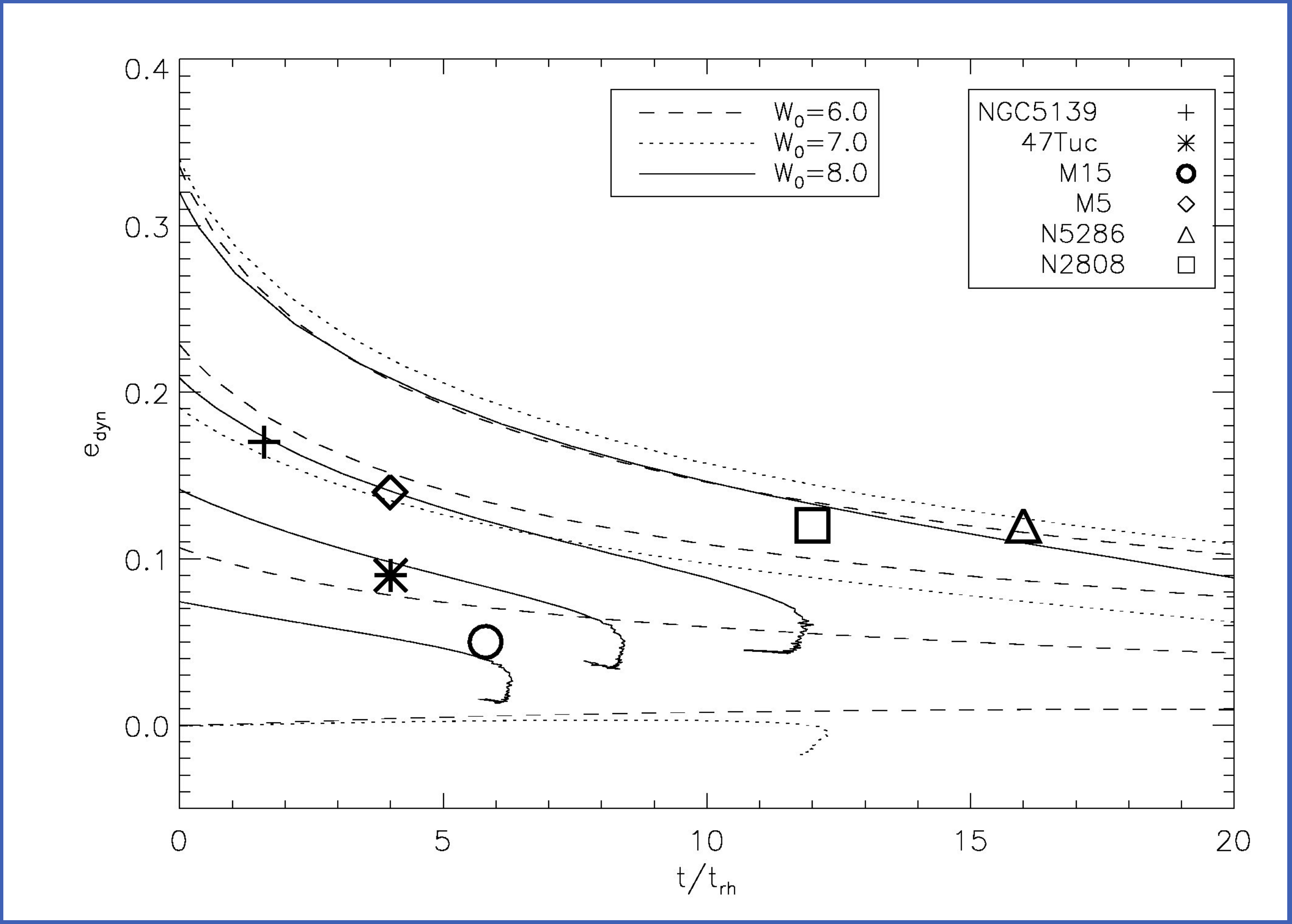
Rotation dominates collapse



Black Holes in Globular Clusters - Results

Set of models:

Ellipticity / concentration vs. time

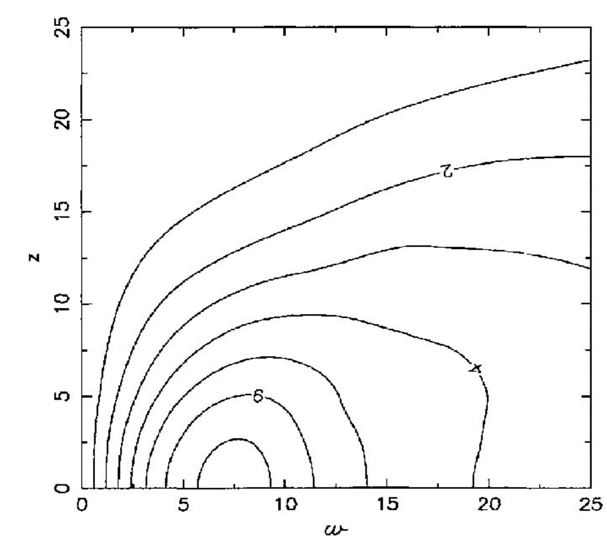


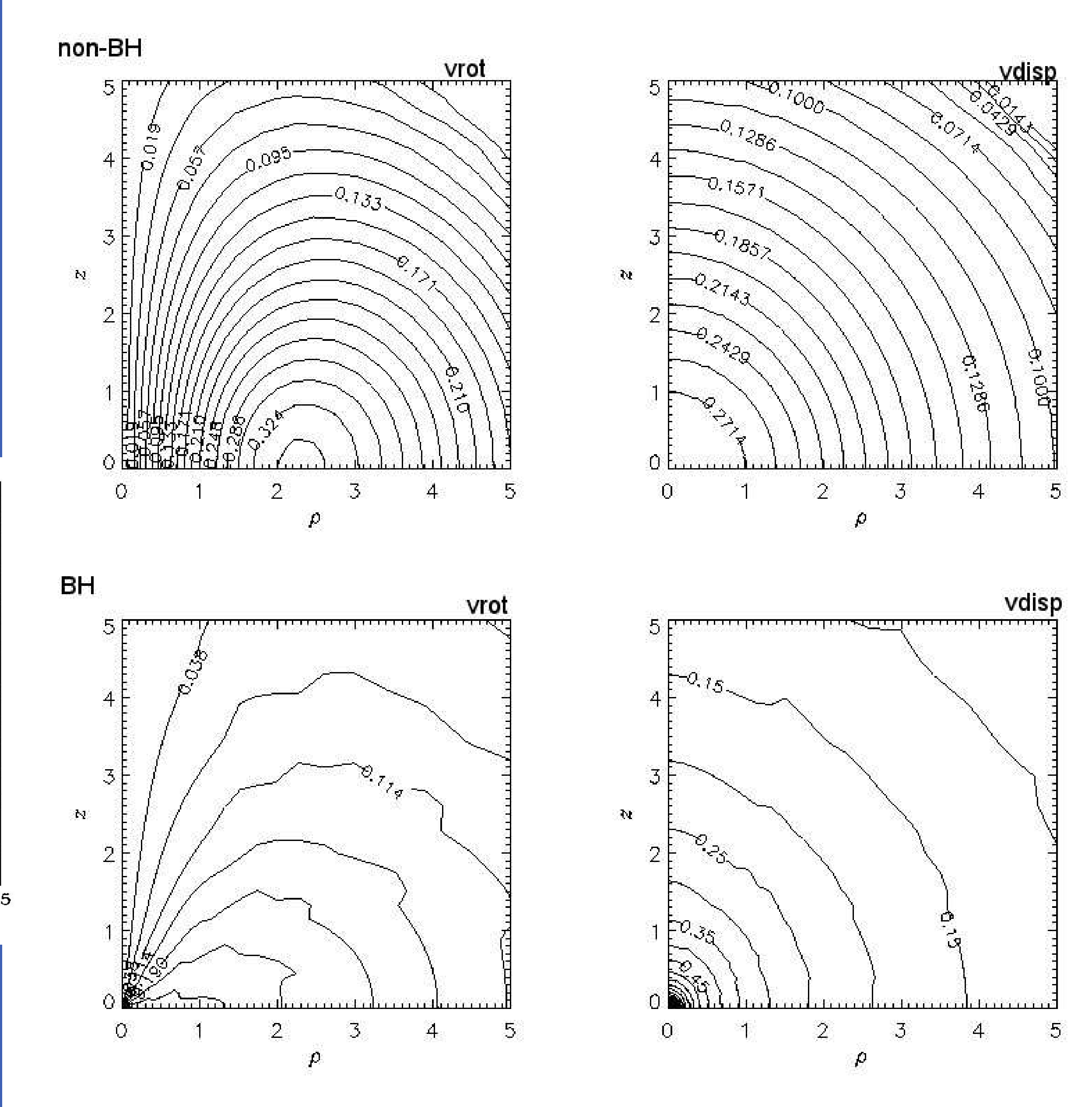
Fiestas et al. (2006)

Black Holes in Globular Clusters - Results

Comparison with observations:

Rotation in the Meridional plane
(Meylan & Mayor, 1986)
(Merritt et al., 1997)

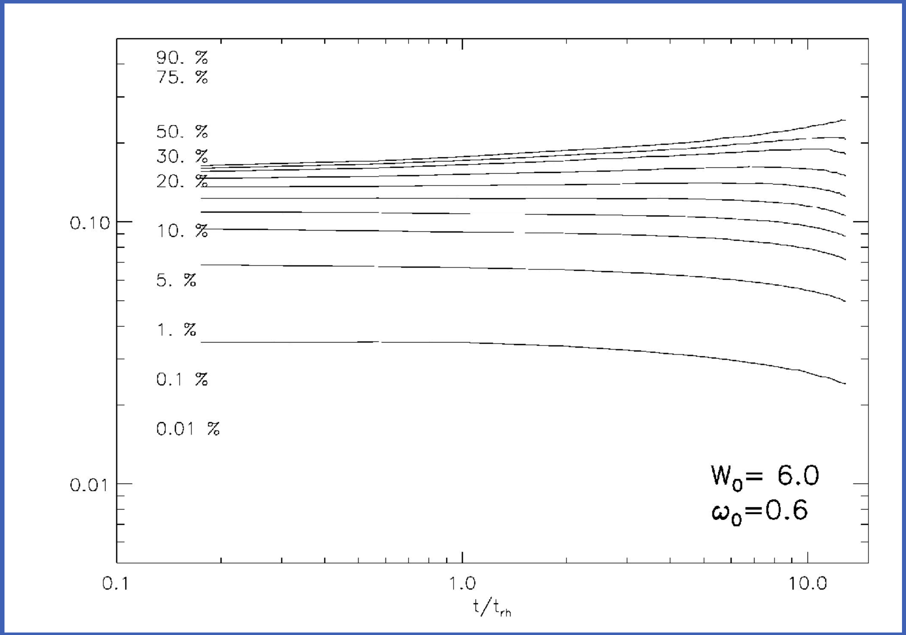




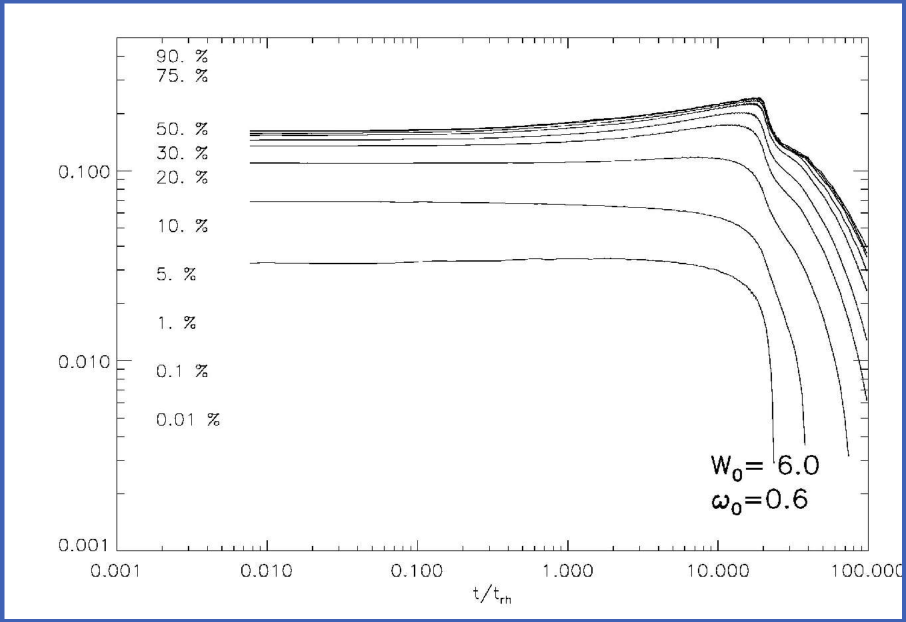
Black Holes in Globular Clusters - Results

Angular velocity:

NO BH:



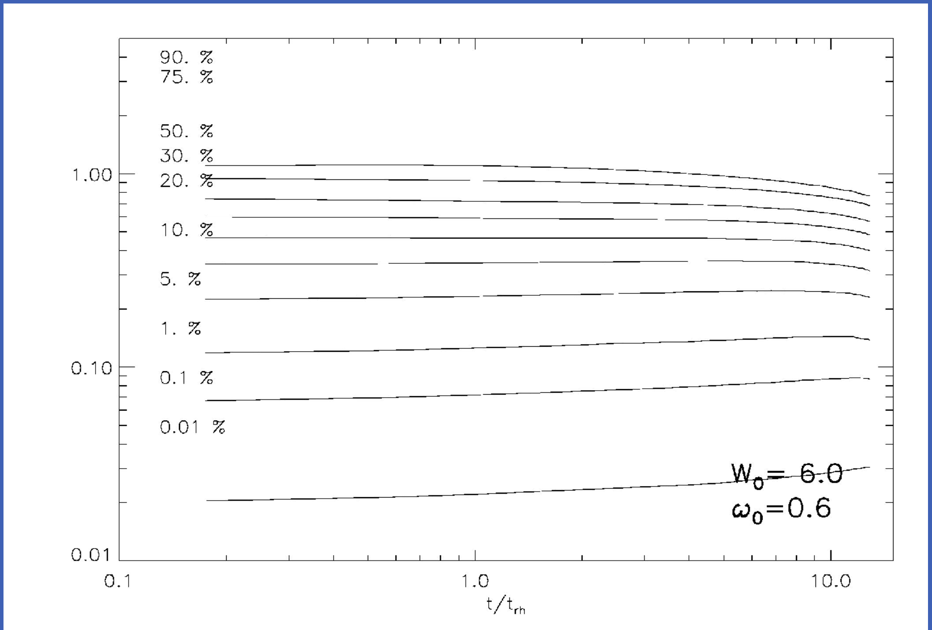
BH:



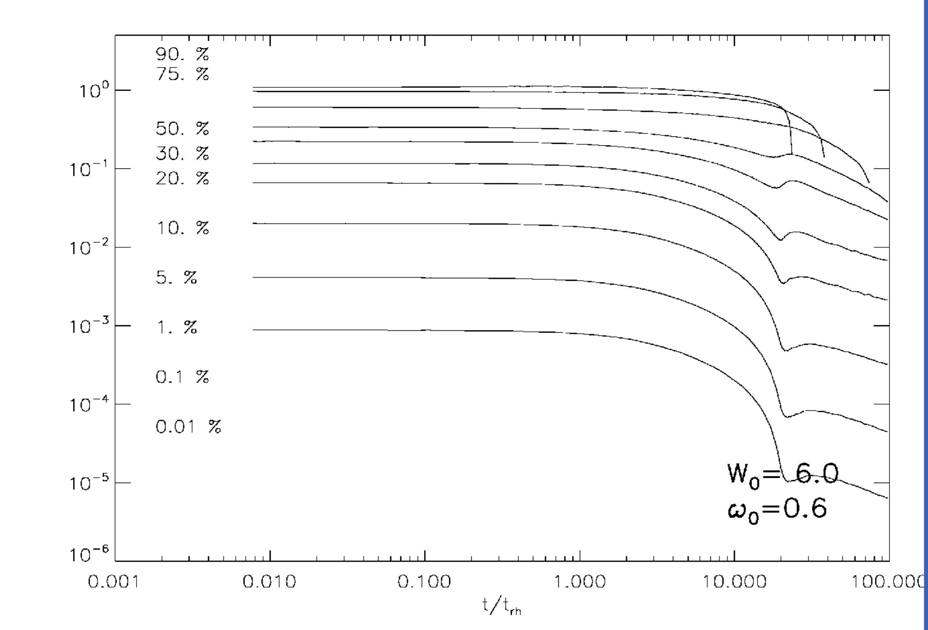
Black Holes in Globular Clusters - Results

Specific angular momentum:

NO BH:



BH:



Black Holes in Globular Clusters - Conclusions

- *Gravogyro + Gravothermal effects drive collapse*

- *Acceleration of evolution due to rotation + BH accretion (faster collapse), and faster mass loss (shortening of life time)*

- *Post-collapse driven by BH energy source*

- *Equilibrium states in density and vel.disp. profiles are as in non-rotating models*

- *Rotation grows in the core limited by angular momentum loss (continuously transported outwards) and BH-accretion efficiency of most low a.m. (radial) orbits.*

- *Data set of models and high resolution in space allows comparison with future observations*

***Future work:** multimass-model, stellar evolution, galaxy tidal field, comparison to N-Body models. Implications in BH mass/sigma correlation*