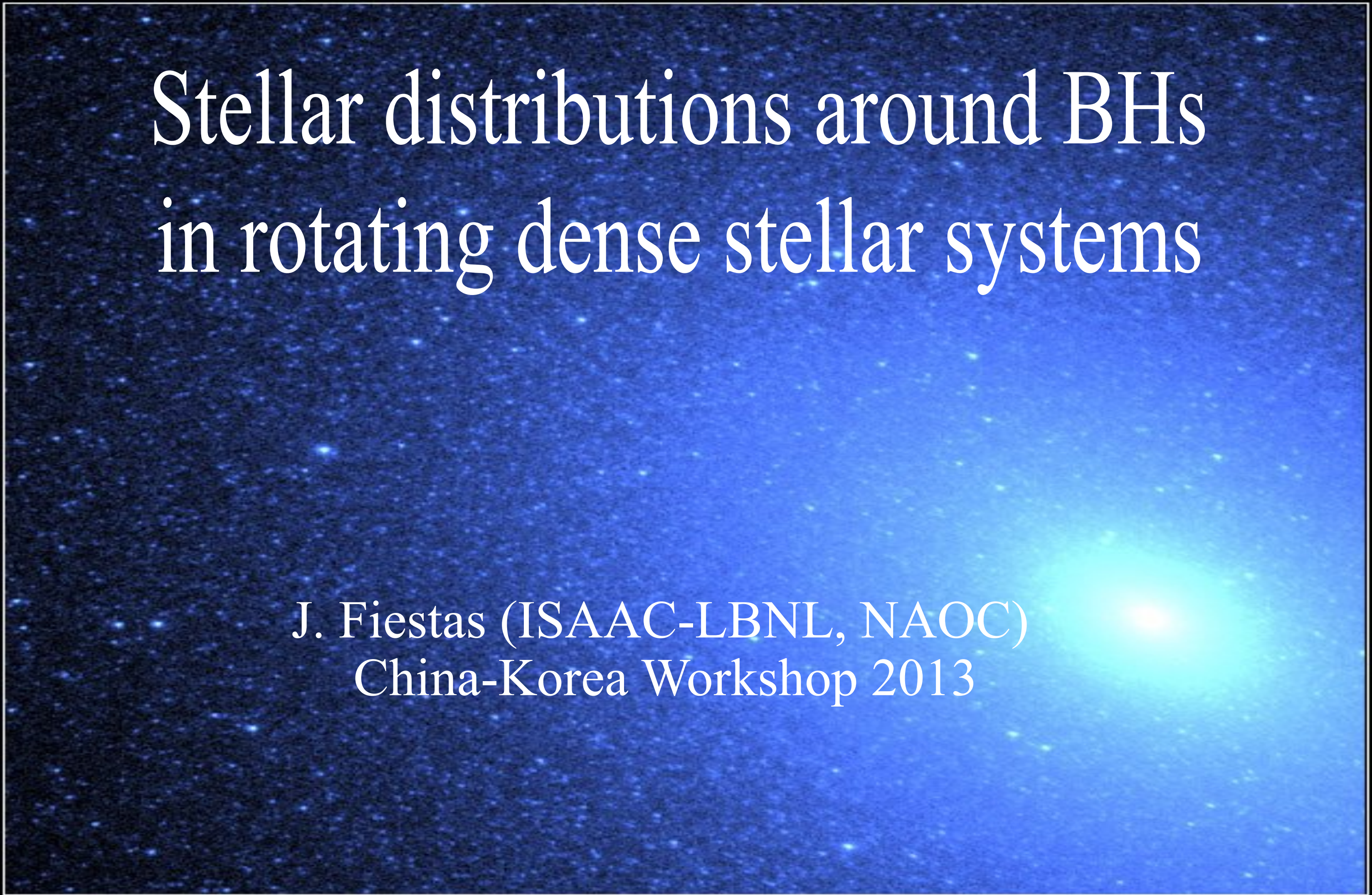


Stellar distributions around BHs in rotating dense stellar systems

J. Fiestas (ISAAC-LBNL, NAOC)
China-Korea Workshop 2013

Dynamics around BHs – rotating systems

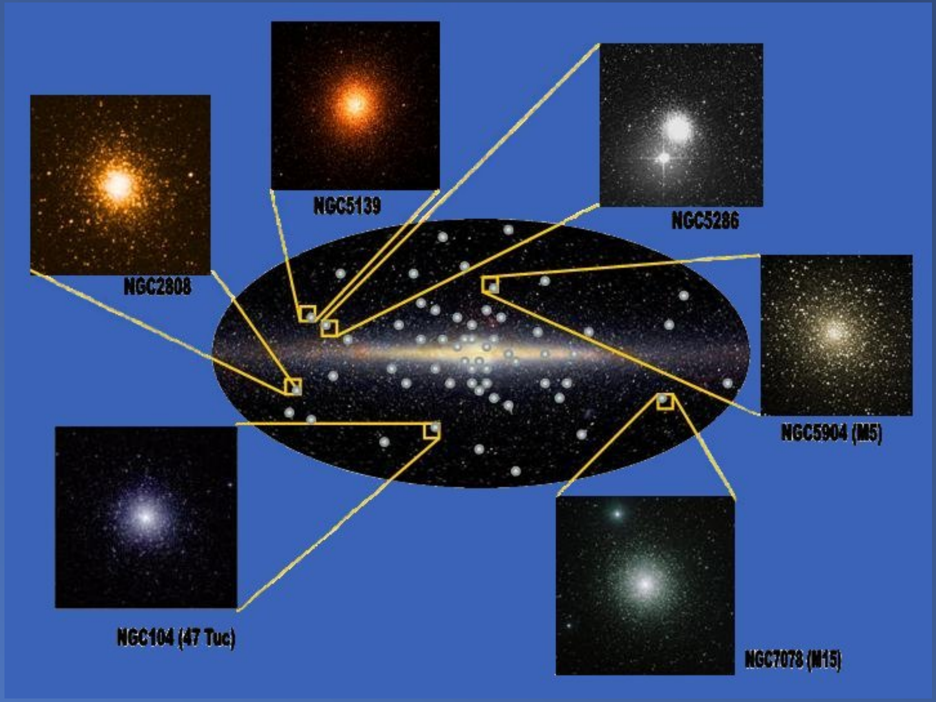
Overview:

- *How rotation modifies dynamics? Rotation in globular clusters and galaxy cores*
- *Models, and simulations with BHs*
- *Recent results of 2-mass component models*

Dynamics around BHs – rotating systems

How internal rotation modifies dynamics:

- *flattening (external tides, pressure anisotropy)*
- *long term dynamical evolution (angular momentum transfer)*
- *gradients in kinematical profiles (differential rotation)*



	$v_{\rm rot}^{\rm max}/\sigma$	e	$T_{\rm rot}/W$
NGC104 (47Tuc)	0.26	0.09	0.025
NGC362	0.01	0.01	0.003
NGC3201	0.28	0.12	0.03
NGC5139 (ω Cen)	0.41	0.17	0.05
NGC5272 (M3)	0.12	0.04	0.01
NGC6205 (M13)	0.25	0.11	0.03
NGC6341 (M92)	0.3	0.10	0.03
NGC6397	0.11	0.07	0.02
NGC6656 (M22)	0.5	0.14	0.04
NGC7078 (M15)	0.15	0.05	0.013
NGC7089 (M2)	0.34	0.11	0.03
NGC7099 (M30)	0.12	0.01	0.003

Dynamics around BHs – rotating systems

Time scale of relaxation:

$$t_{\rm r} \approx 0.065\ \sigma^3/(G^2 m_\star \rho \ln \Lambda)$$

E4 M49 (AURA, NSF, NOAO)

Collisionless systems:

relax. times exceed Hubble time
e: 0.0 – 0.7
Ellipticity supported by vel.disp and rotation

47 Tuc (ESO/Danish 1.54-m/W.Keel)

Collisional system:

relax. times much smaller than Hubble time
e: 0.0 – 0.2
Flattened systems become sphericall as they relax
(Shapiro & Marchant 1976
Fall & Frenk 1984,
White & Shawl 1987)

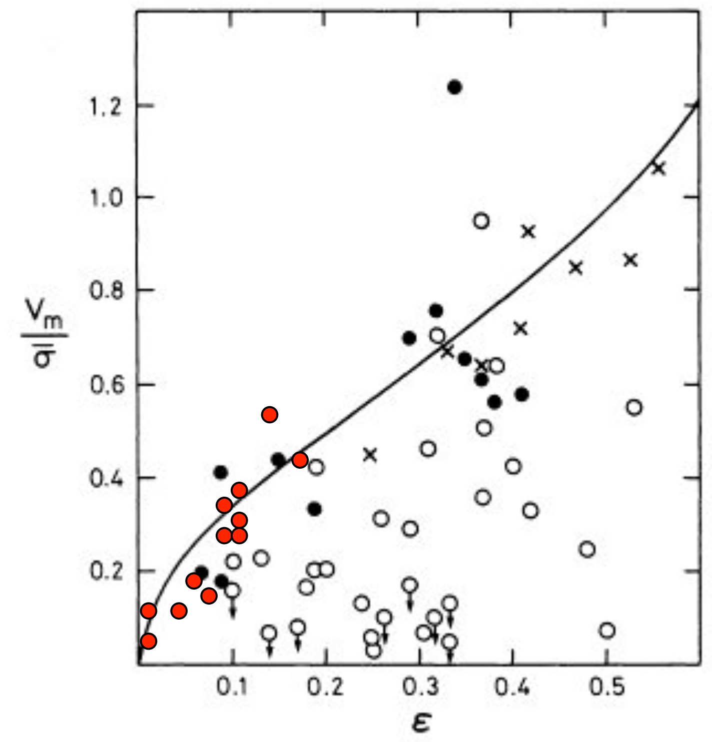


FIG. 3.—The quantity $V_m/\bar{\sigma}$ against ellipticity. Ellipticals with $M_B^{\rm UH} > -20.5$ are shown as filled circles; ellipticals with $M_B^{\rm UH} < -20.5$, as open circles; and the bulges of disk galaxies, as crosses. The solid line shows the $(V/\sigma, \epsilon)$-relation for oblate galaxies with isotropic velocity dispersions (Binney 1978).

● MW Globular clusters

See also Lutzgendorf et al (2013) for m-sigma relation

Dynamics around BHs – rotating systems

GC fitting using Fokker-Planck models:

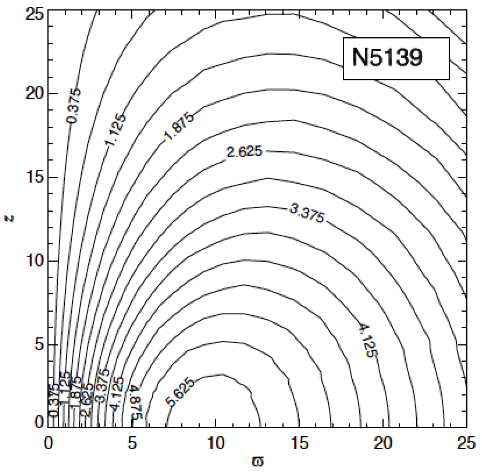
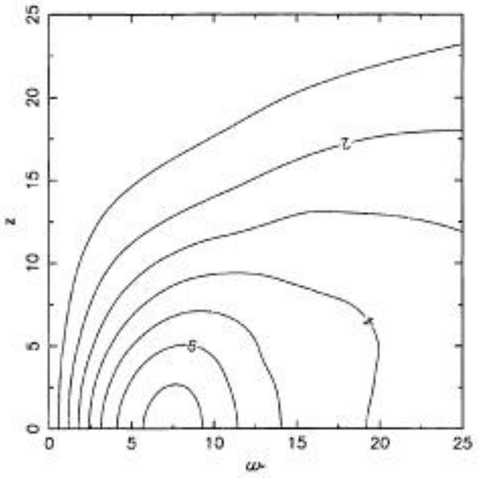
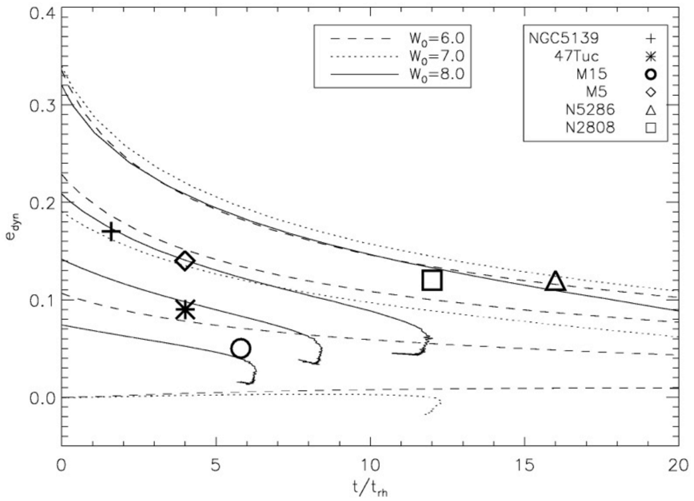


Figure 9. Same as Fig. 7 for a model of ωCen. $W_0 = 6$, $\omega_0 = 0.5$ and $t/t_{\rm rh} = 1.6$



Estimate of the mean azimuthal velocity $\bar{v}_\phi$ in the meridional p
entauri, obtained as the solution to the optimization problem
es are in arc minutes and contours are labelled in km s^{-1}.



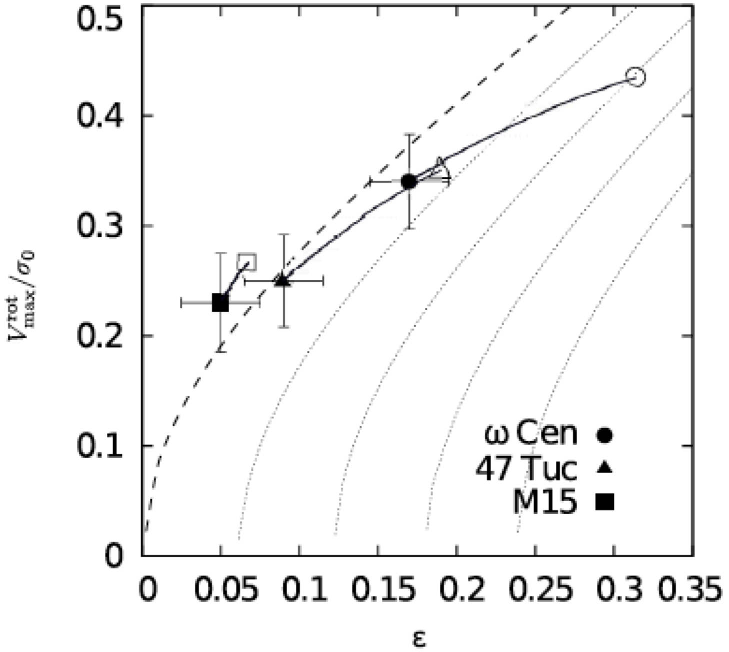
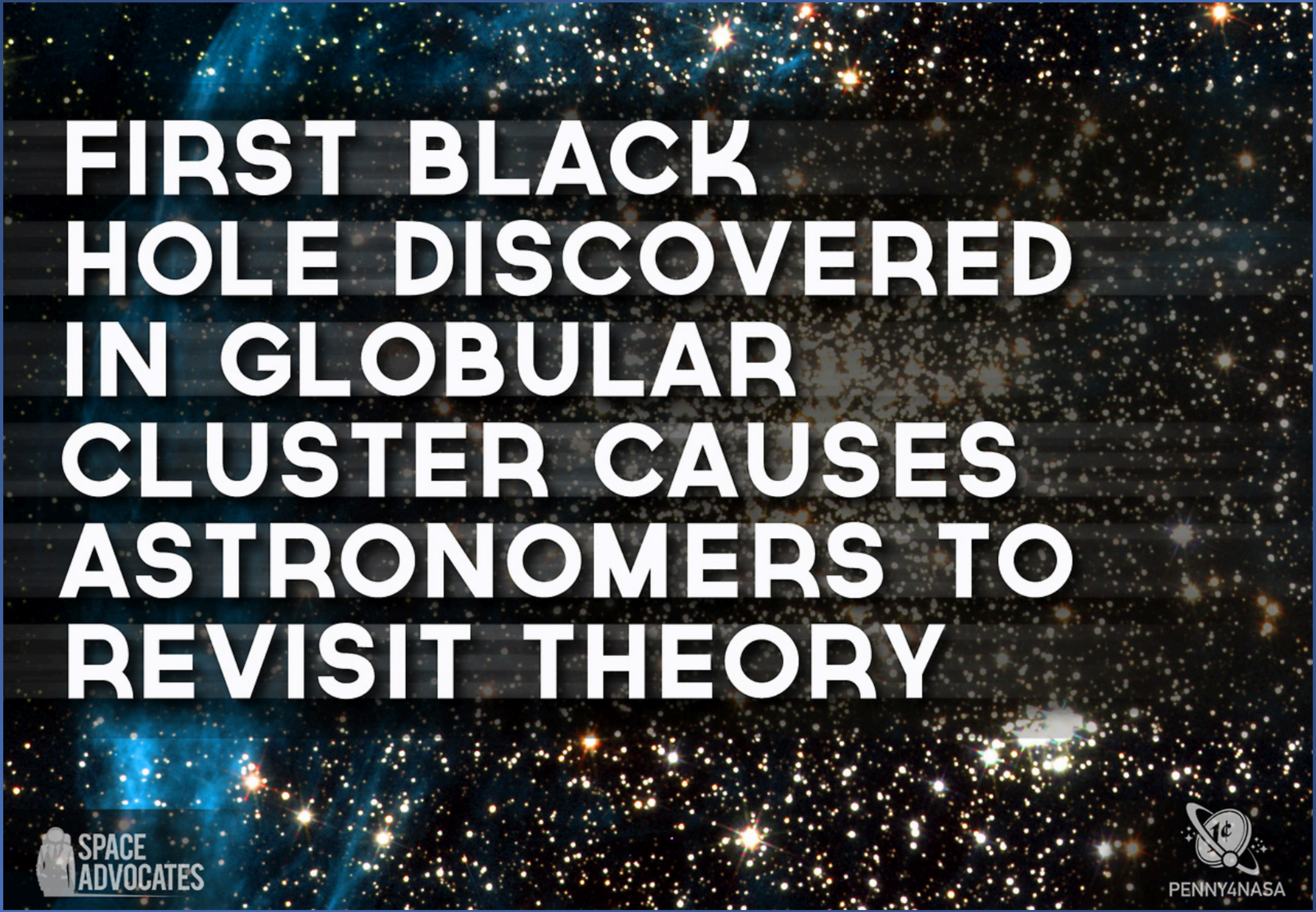


Figure 14. V/σ vs. ellipticity ε for ω Cen, 47 Tuc, and M15. The filled symbols denote the pairs (V/σ, ε), in which the ellipticity values are determined by WS87. The empty symbols, connected by a segment to the associated filled symbols, indicate the pairs (V/σ, ε) corrected for inclination. The dashed line indicates the relation for isotropic oblate rotators viewed "edge-on," whereas the thin dotted lines indicate oblate rotators viewed "edge-on" with different global anisotropy parameters δ (from left to right, $\delta = 0.05$, 0.1, 0.15, and 0.20). See the text for a more complete description.

Fiestas et al (2006)

Bianchini et al (2013)

Dynamics around BHs – rotating systems



FIRST BLACK HOLE DISCOVERED IN GLOBULAR CLUSTER CAUSES ASTRONOMERS TO REVISIT THEORY

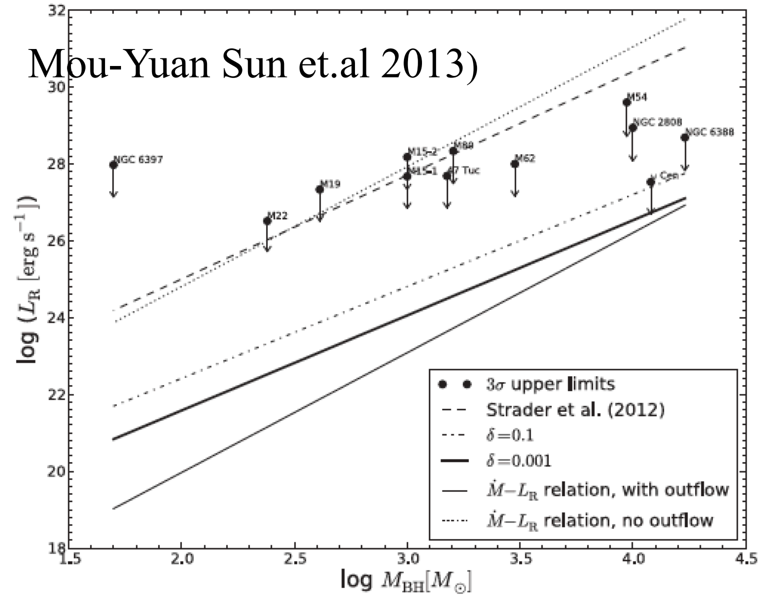
Dynamics around BHs – rotating systems

Are there IMBHs in GCs?

IMBH $\sim 10^4$

- *100-1000 $M_\odot$, core collapse, dynamical evolution*
- *many will be ejected (3-body encounters, mergers)*
- *runaway growth of seeds (or partial energy equipartition ?- Trenti & Van der Marel (2013)*
- *Observational evidence ?*

M15 -> 3.9 x 10^3 M_sun (Gerssen et al. 2002, 2003) ,
G1 (M31) -> 2 x 10^4 M_sun (Gebhardt et al. 2002)

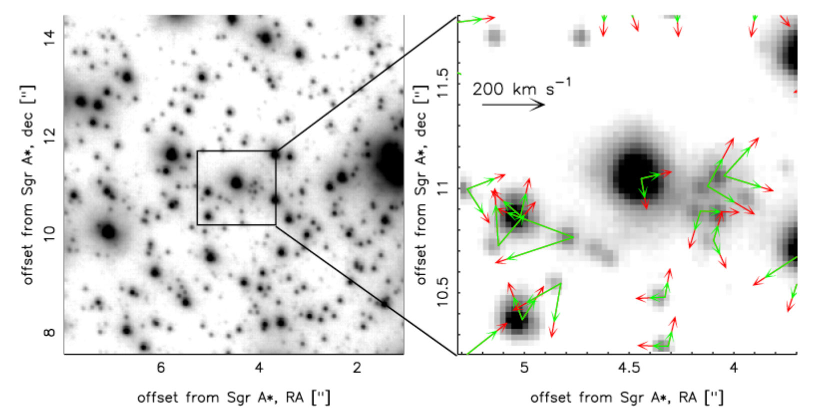


Mou-Yuan Sun et.al 2013)

Figure 1. Radio luminosity L_R as a function of black hole mass M_{BH}. The filled circles represent the 3σ upper limit of L_R for each source, where the black hole masses are constrained via dynamical modelings. The dashed line represents the predicted L_R as a function of M_{BH} according to Strader et al. (2012). The dot–dashed line and the thick solid line correspond to our new results with $\delta = 0.1$ and 0.001, respectively. The thin solid line and the dotted line represent L_R estimated by the $\dot{M} - L_R$ relation instead of the fundamental plane relation with and without outflows, respectively.

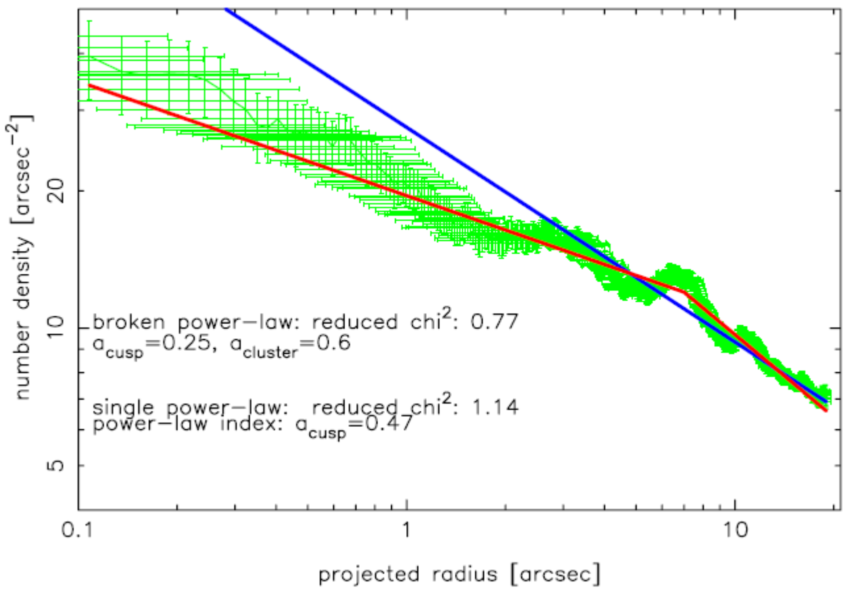
Dynamics around BHs – rotating systems

Relaxed systems reach steady states with density cusps of -1.75 (Bahcall & Wolf, 1976,77)



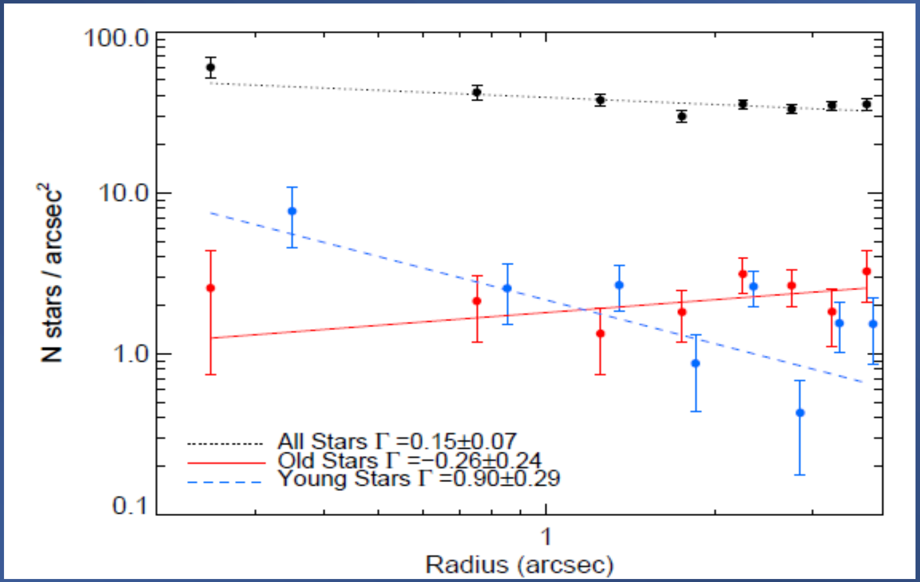
Schödel et al. (2007)

Our galaxy:



$\rho(r) \sim r^\gamma$

$-1.5 < \gamma < -1.75$



Do et al. (2011)

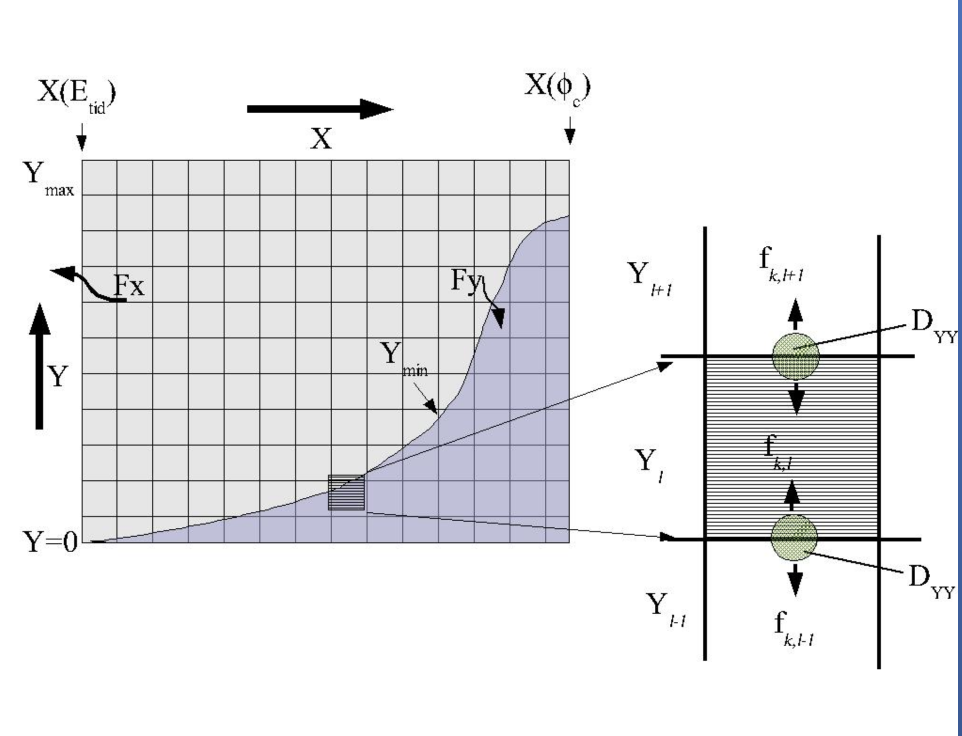
$\gamma < -1.$

Simulations with BHs

Dynamics around BHs – rotating systems

Fokker-Planck approximation (axisymmetric model):

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



Fiestas. (2006)

Direct N-Body models:

- *Hermite integration*
- *Individual/block time steps*
- *Ahmad-Cohen neighbour scheme*
- *KS-regularization*

$$\ddot{\mathbf{r}}_i = -G\sum_{j\neq i} m_j \frac{\mathbf{r}_i - \mathbf{r}_j}{|\mathbf{r}_i - \mathbf{r}_j|^3}.$$

Stellar accretion:

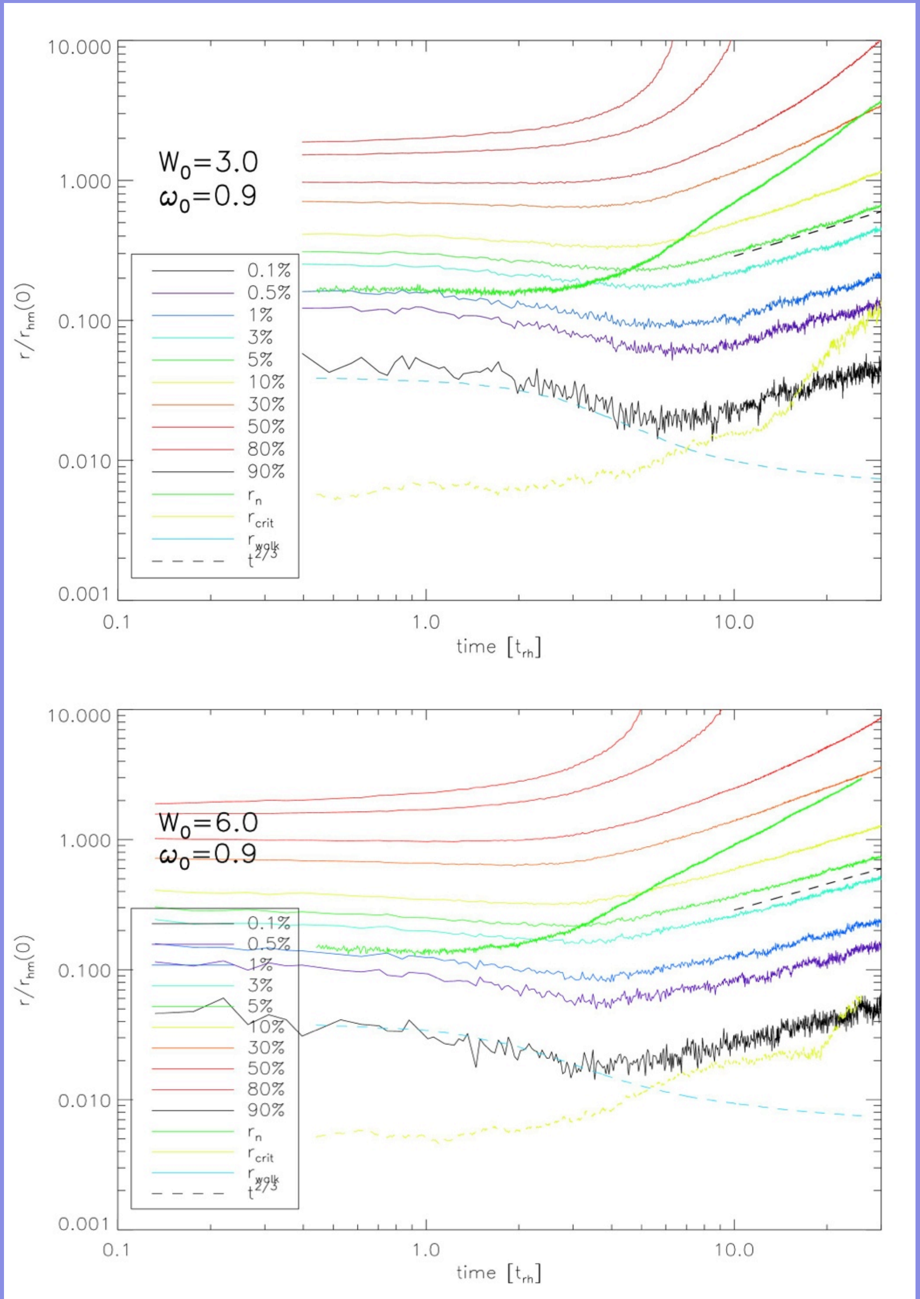
$$r_{\mathrm{d}} \sim r_*(M_{\mathrm{bh}}/m_*)^{1/3}$$

Dynamics around BHs – rotating systems

Evolution of Lagrangian-Radii:

Core collapse is prevented, further expansion of outer layers

Massive BHs "turn-off" core-collapse, driven by heating from stellar disruption



Collisional evolution due to rotation + BH accretion

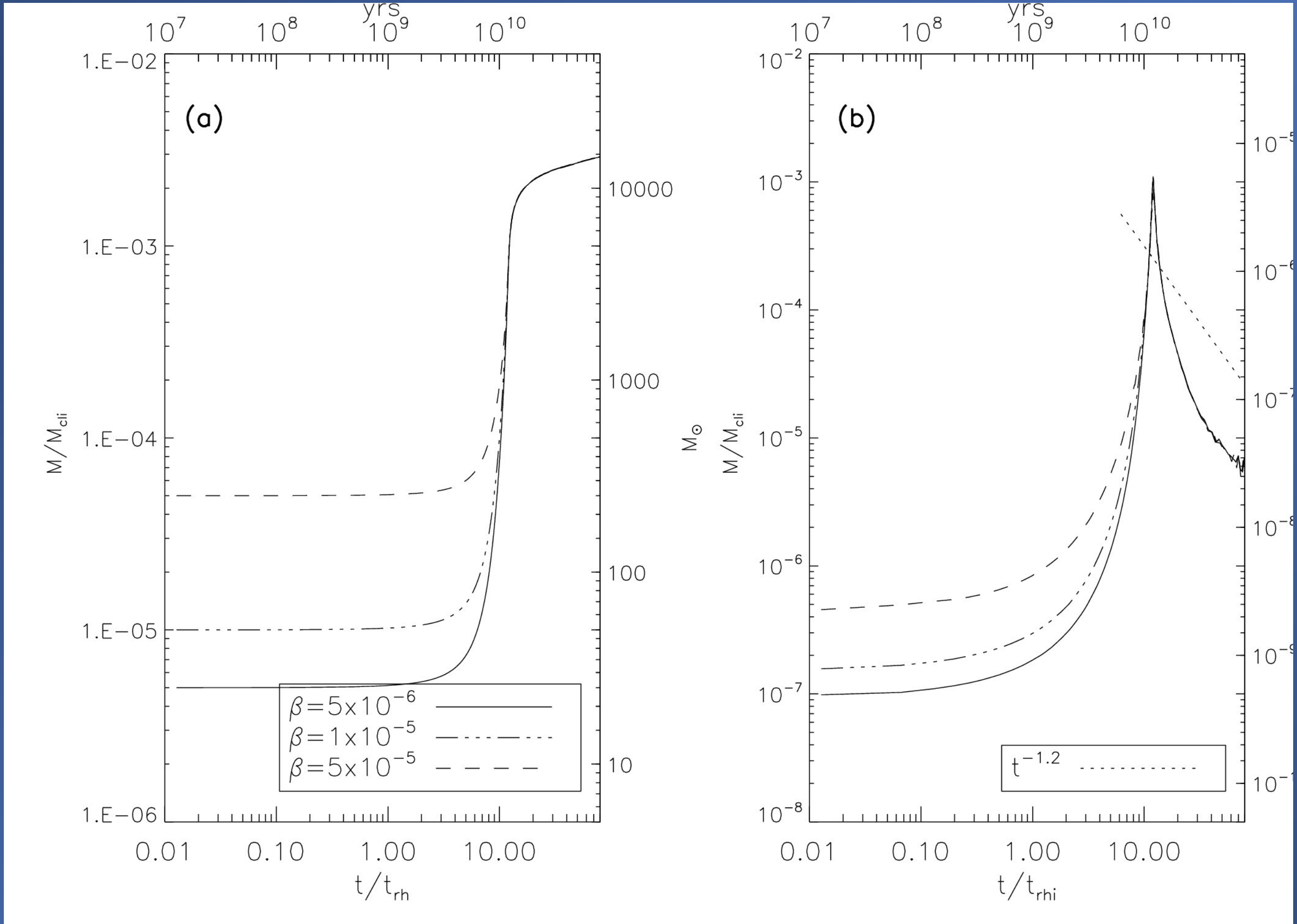
Fiestas et al. (2011)

Dynamics around BHs – rotating systems

Evolution of BH-mass and disruption rates (axisymmetric models)

Left: Final BH mass independent of initial conditions

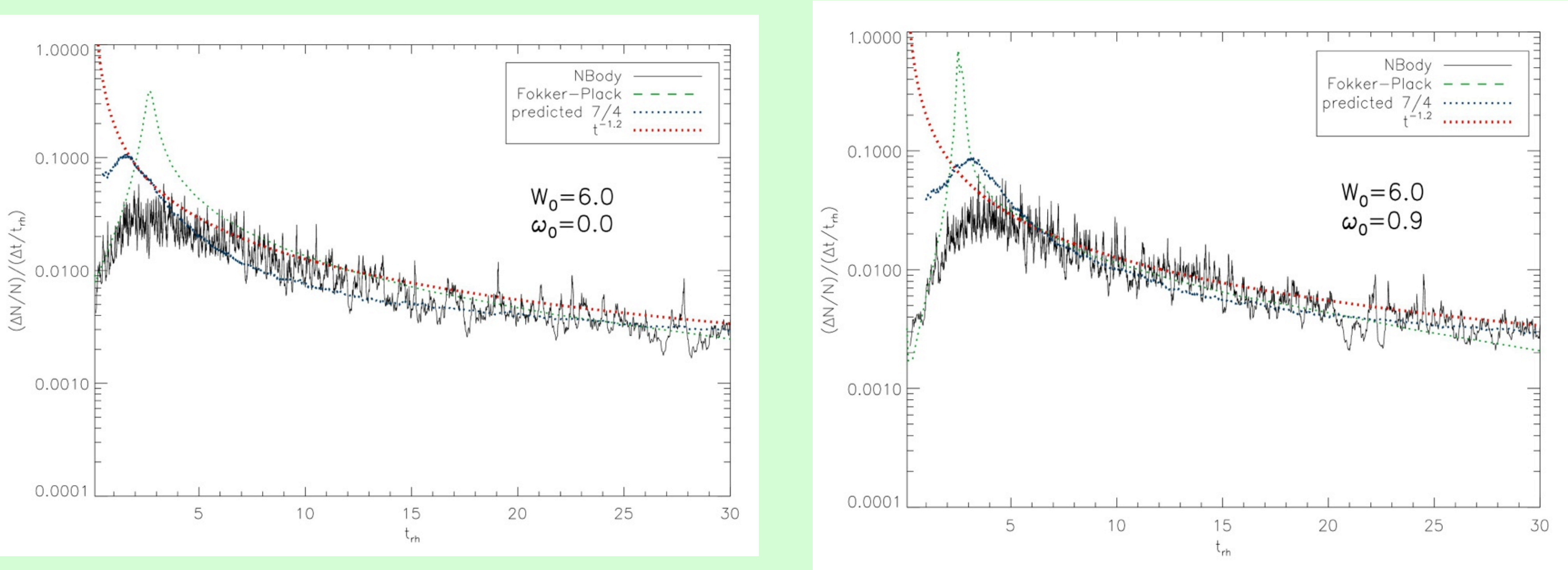
Right: Mass loss rates enhanced by core contraction with a maximum at collapse time



Fiestas & Spurzem (2010)

Dynamics around BHs – rotating systems

Disruption rates:
compact cores



Time averaged disruption rates in Nbody models (black)
in comparison to FP models (green).
Red line is the analytical solution for Bahcall-Wolf cusp

Fiestas et al. (2011)

Dynamics around BHs – rotating systems

Disruption rates:

Average loss-rate:
M_tot=10^9 M_sun,
T_rh= 10^10 yr

dM/dt = 3.13 x 10^-4 M_sun/yr

e.g. rate of large amplitude X-ray outbursts from active/inactive galaxies:
1.5 x 10^-5 galaxy^-1 yr^-1
(Donley et al.2002)

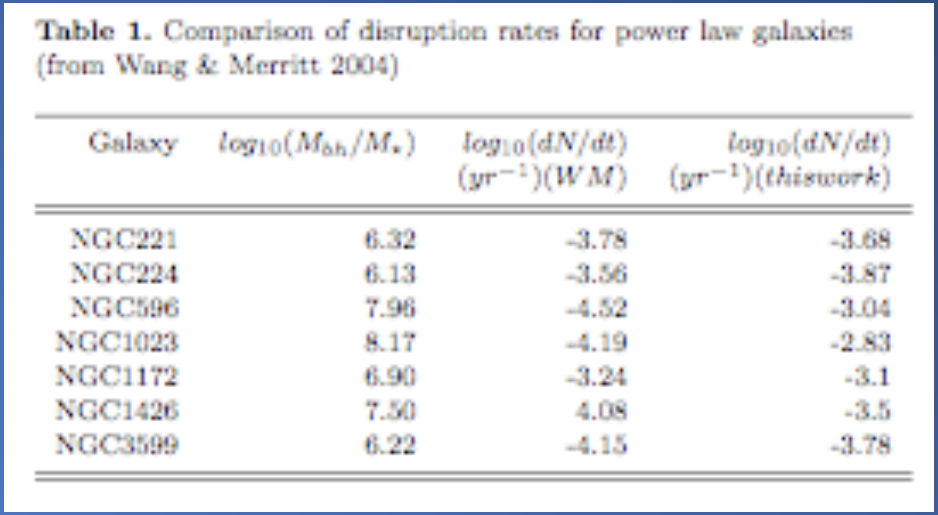
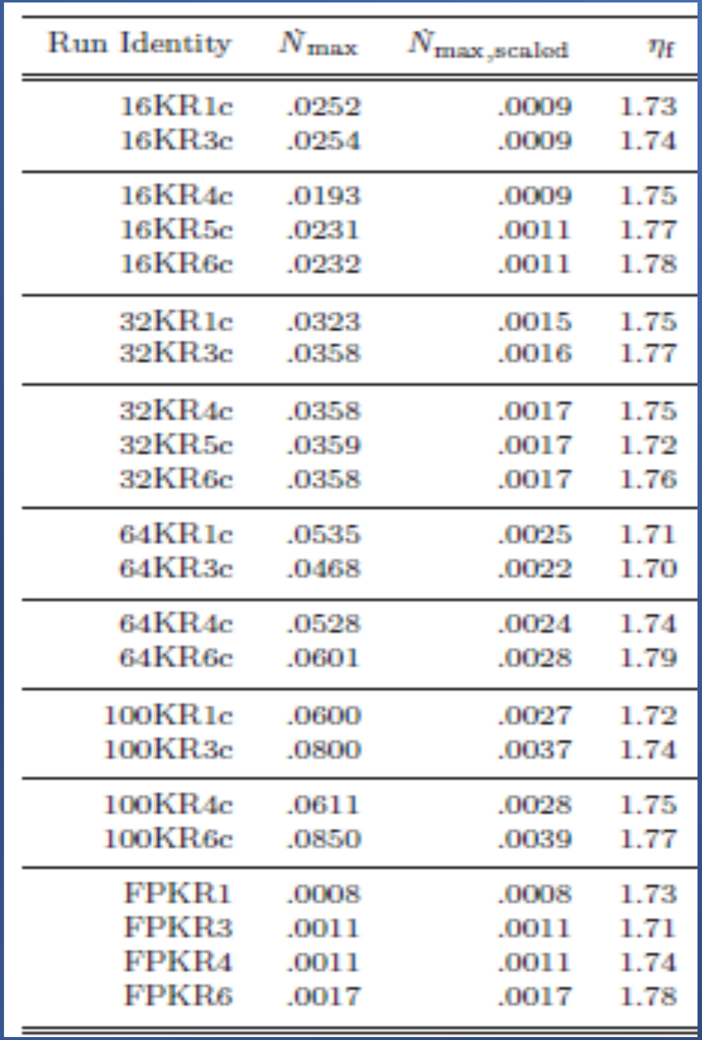


Table 1. Comparison of disruption rates for power law galaxies (from Wang & Merritt 2004)

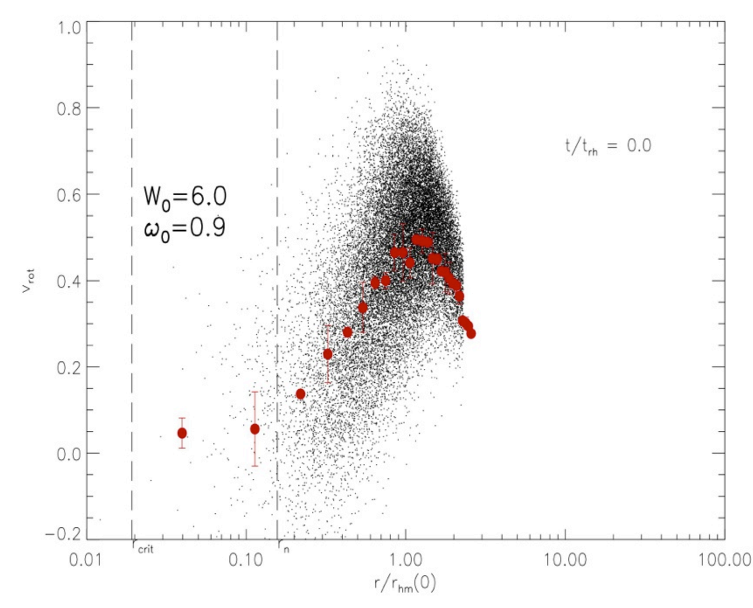
Galaxy	$log_{10}(M_{bh}/M_*)$	$log_{10}(dN/dt)$ $(yr^{-1})(WM)$	$log_{10}(dN/dt)$ $(yr^{-1})(thiswork)$
NGC221	6.32	-3.78	-3.68
NGC224	6.13	-3.56	-3.87
NGC596	7.96	-4.52	-3.04
NGC1023	8.17	-4.19	-2.83
NGC1172	6.90	-3.24	-3.1
NGC1426	7.50	4.08	-3.5
NGC3599	6.22	-4.15	-3.78



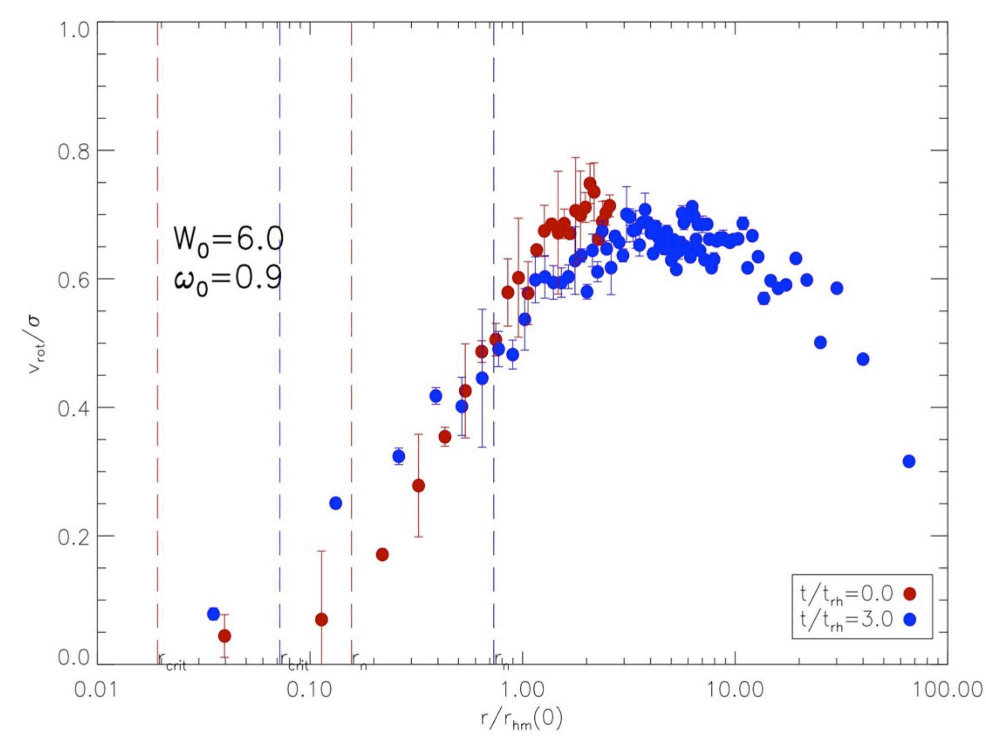
Run Identity	$\dot{N}_{\max}$	$\dot{N}_{\max,\mathrm{scaled}}$	η_f
16KR1c	.0252	.0009	1.73
16KR3c	.0254	.0009	1.74
16KR4c	.0193	.0009	1.75
16KR5c	.0231	.0011	1.77
16KR6c	.0232	.0011	1.78
32KR1c	.0323	.0015	1.75
32KR3c	.0358	.0016	1.77
32KR4c	.0358	.0017	1.75
32KR5c	.0359	.0017	1.72
32KR6c	.0358	.0017	1.76
64KR1c	.0535	.0025	1.71
64KR3c	.0468	.0022	1.70
64KR4c	.0528	.0024	1.74
64KR6c	.0601	.0028	1.79
100KR1c	.0600	.0027	1.72
100KR3c	.0800	.0037	1.74
100KR4c	.0611	.0028	1.75
100KR6c	.0850	.0039	1.77
FPKR1	.0008	.0008	1.73
FPKR3	.0011	.0011	1.71
FPKR4	.0011	.0011	1.74
FPKR6	.0017	.0017	1.78

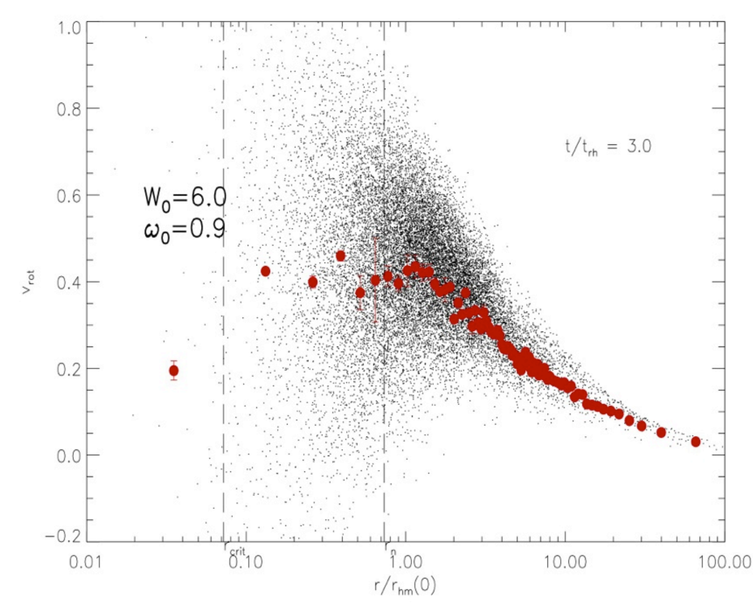
Fiestas et al. (2011)

Dynamics around BHs – rotating systems



Evolution of rotational velocity profiles

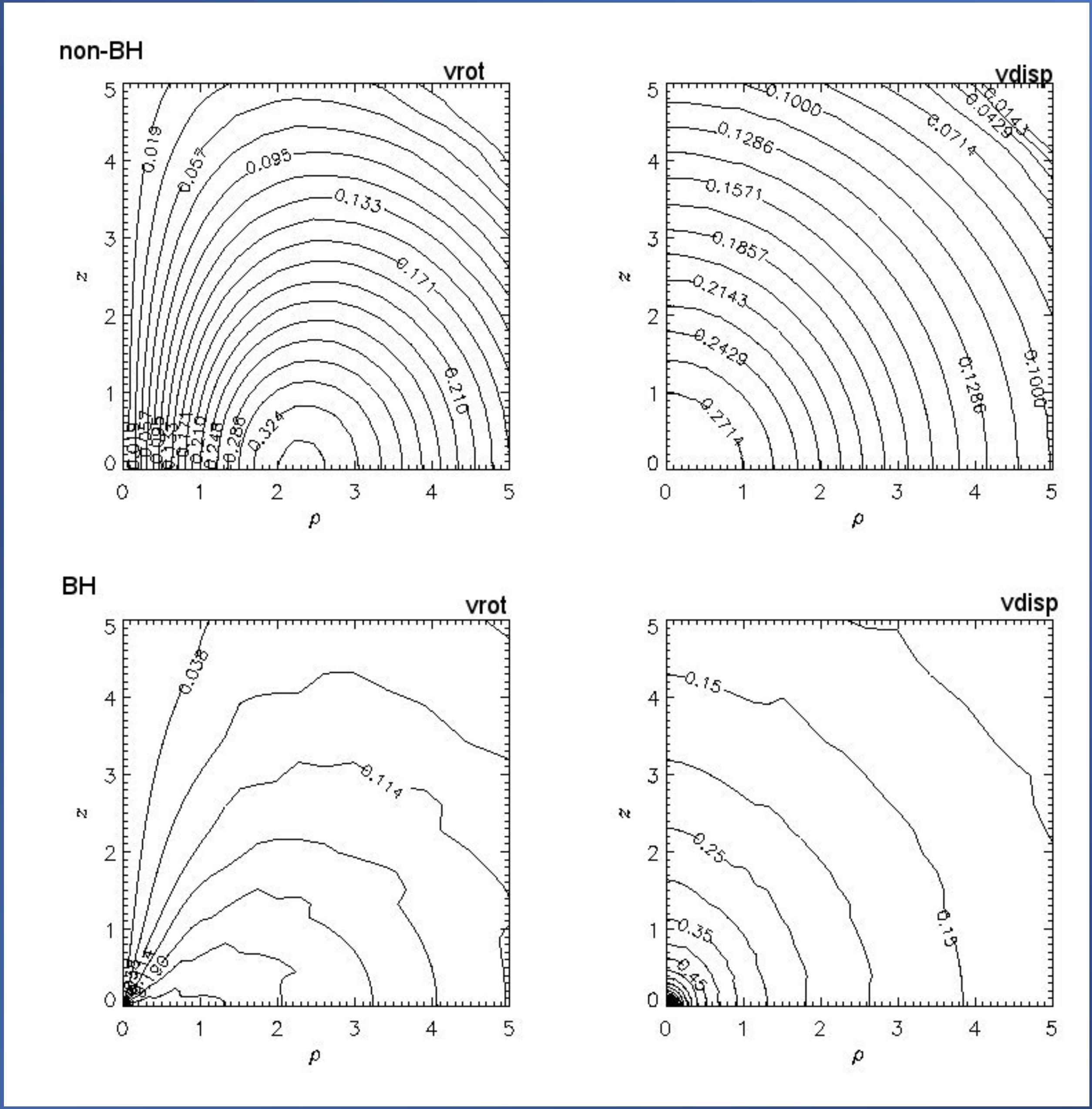




Fiestas et al. (2011)

Dynamics around BHs – rotating systems

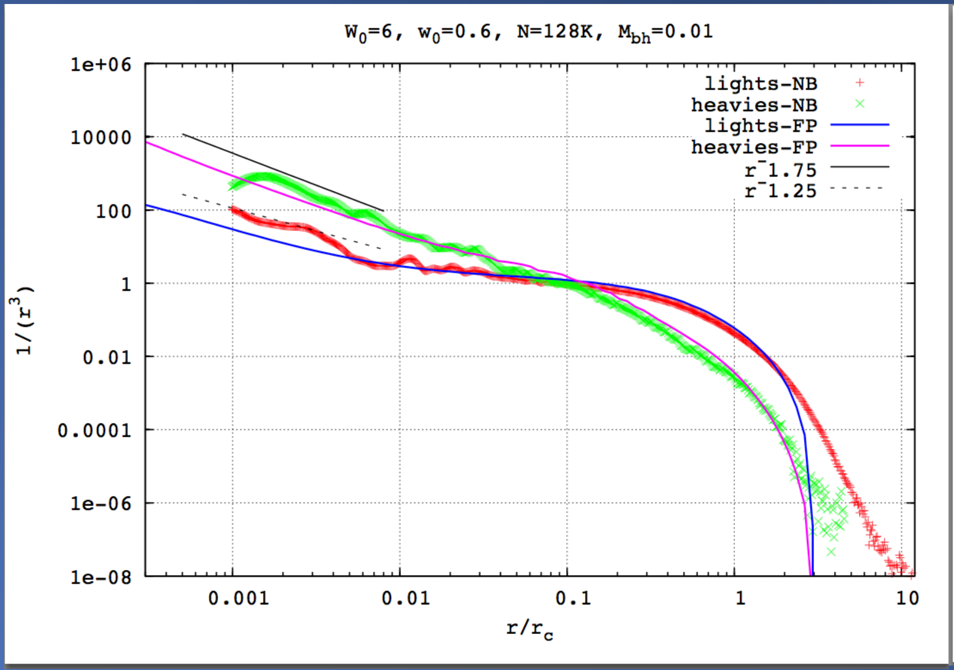
Rotation and dispersion maps in the meridional plane. Useful for observations (Fokker-Planck data)

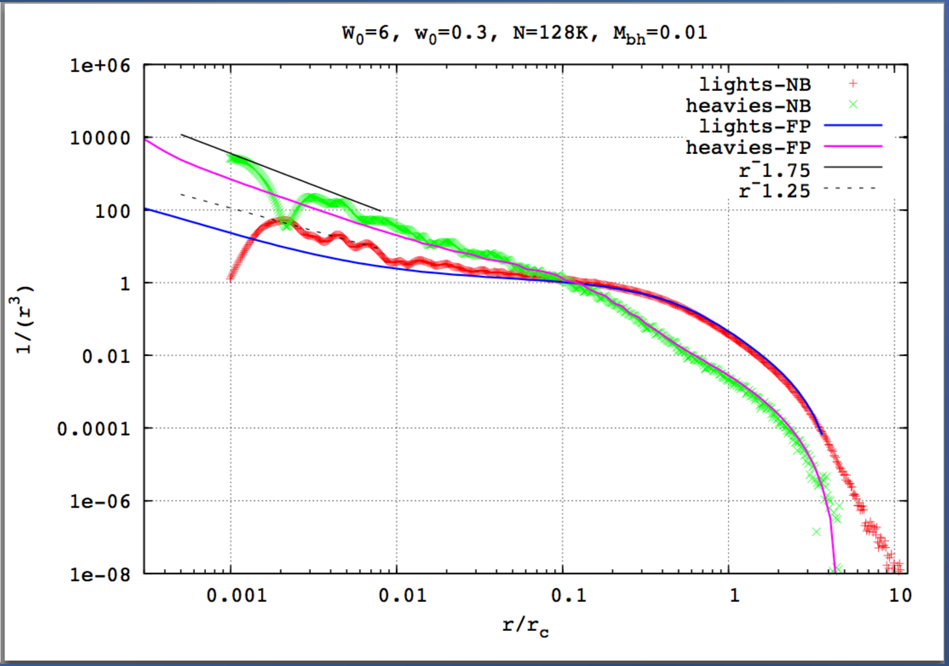


Fiestas (2006)

Dynamics around BHs – rotating systems

Recent results of 2-mass component models with a central BH: $N_h/$
$N_h/N_{tot}=0.01$, $m_h/m_l = 10$
Steady-state Bahcall-Wolf cusp ~ -1.75 reached by heavy stars
Ligther stars show lower cusps than expected ~ -1.5 (BW77)

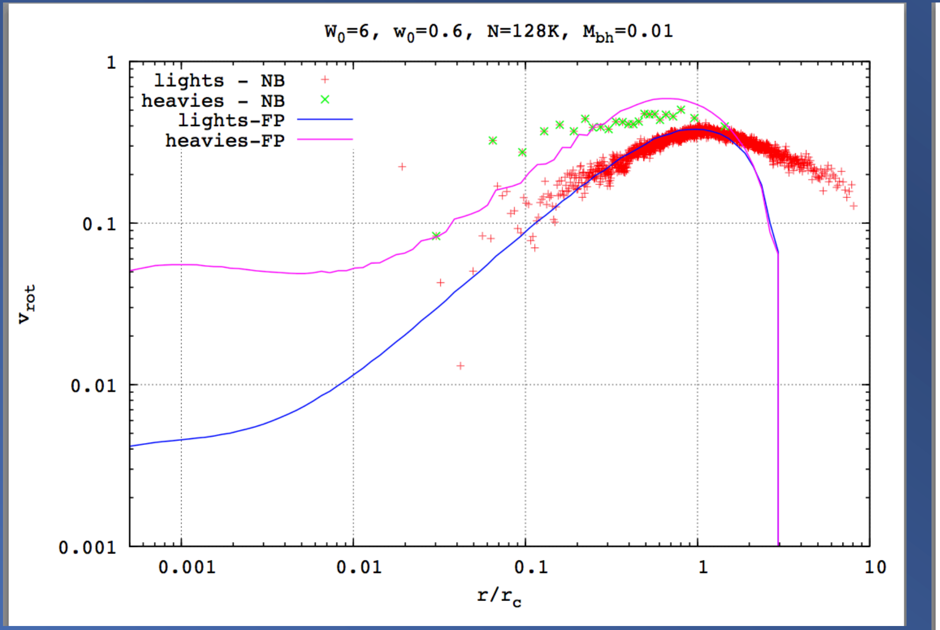


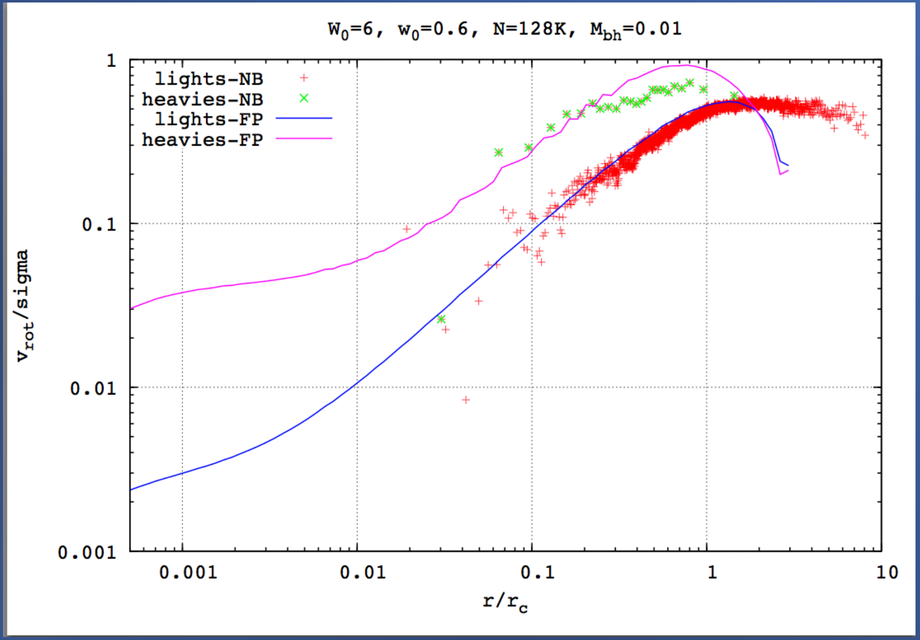


Fiestas et al. (2014), in prep.

Dynamics around BHs – rotating systems

Rotational velocity and v_{rot}/σ at t_rh~0.8
Heavy stars segregate and take angular momentum to the center.

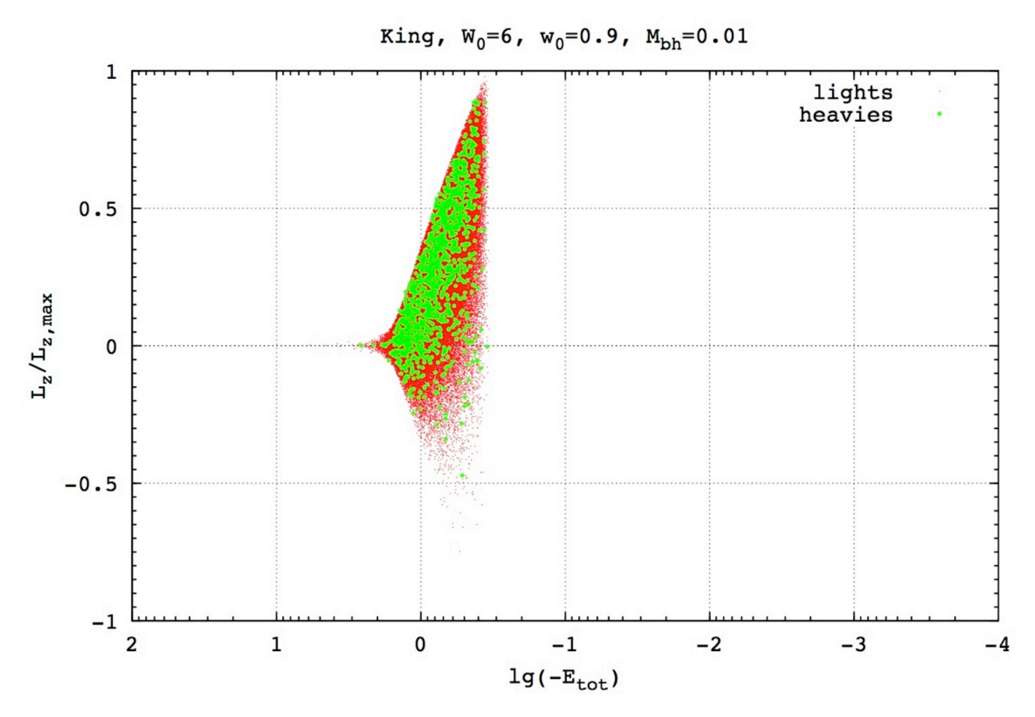




Fiestas et al. (2014), in prep.

Dynamics around BHs – rotating systems

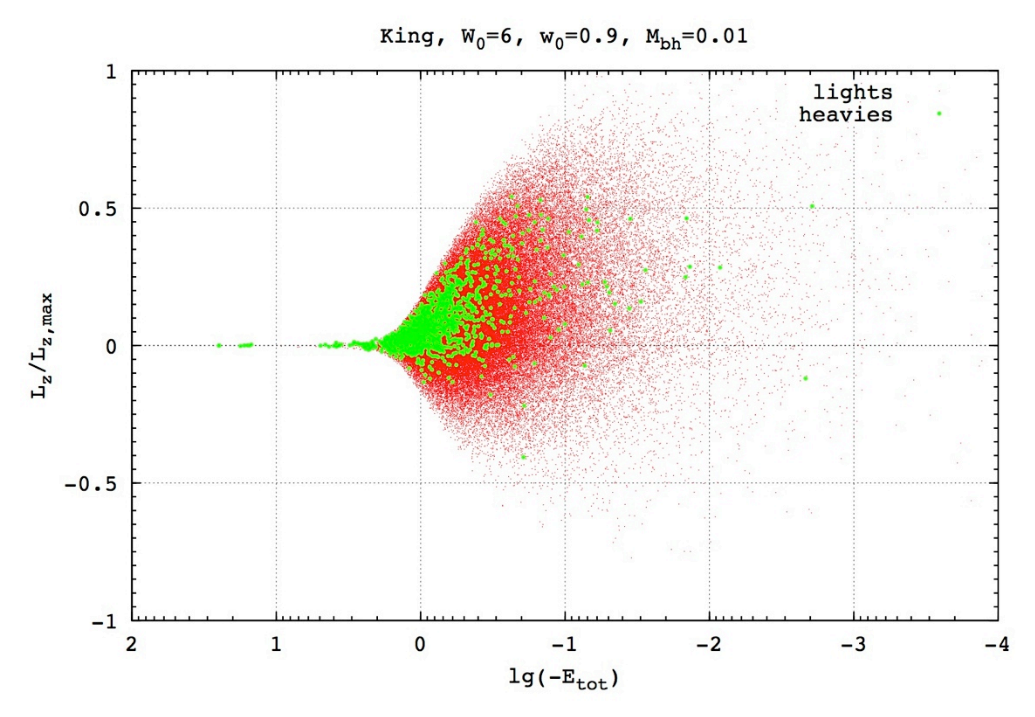
E-Jz distributions of stars at t/t_{rh} = 0.0 *(*W_0=0.6 , ω_0=0.9*)*
Initial asymmetric distribution of light and heavy stars.



Fiestas et al. (2014), in prep.

Dynamics around BHs – rotating systems

E-Jz distributions of stars at $t/t_{rh} \sim 0.8$ $(W_0=0.6\ ,\ \omega_0=0.9)$
Asymmetric distribution shows strong rotation, dominated by heavy stars.



Fiestas et al. (2014), in prep.

Dynamics around BHs – rotating systems

Conclusions:

- *Axisymmetric cores with BHs develop steady-state solutions and central rotation in a time of the order of a relaxation time.*

- *Light stars in 2-mass models show lower cusps, like the observed in our galaxy, probably as a consequence of relaxation processes*

Future work:

- *stellar evolution → faster dynamical evolution!*