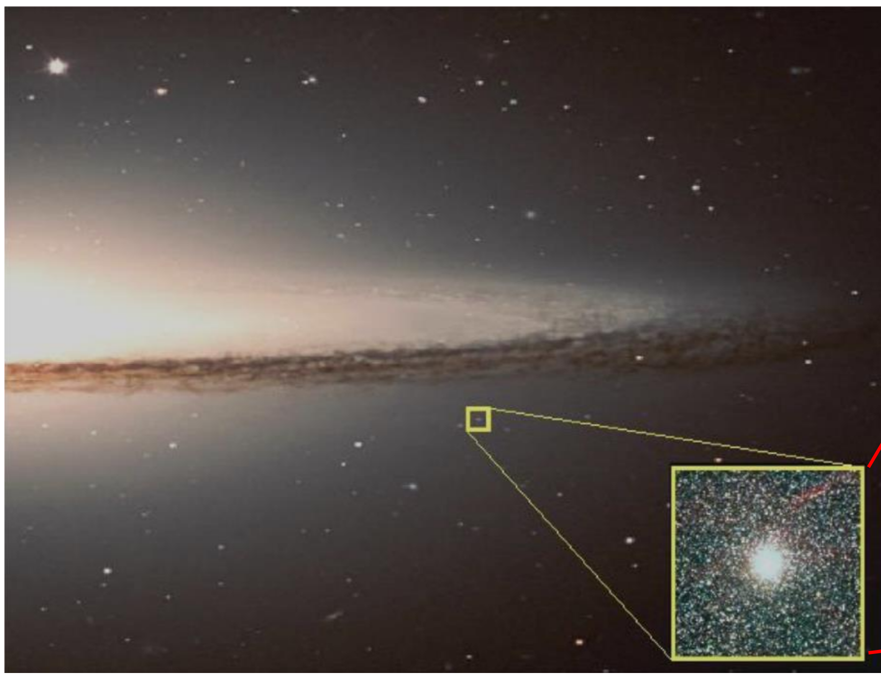
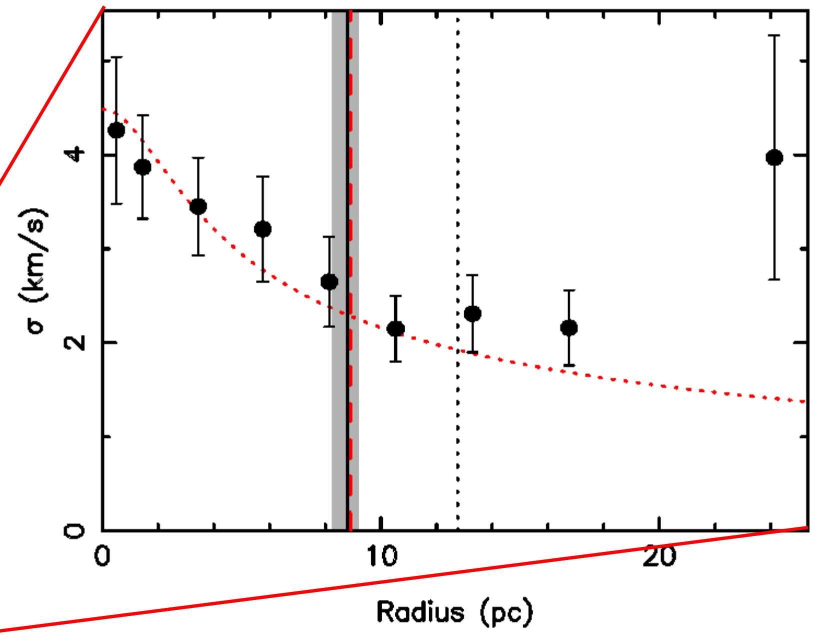
The role of three-body stability in tidally interacting globular clusters





Gareth Kennedy

gareth.f.kennedy@gmail.com

中国科学院国家天文台
NATIONAL ASTRONOMICAL OBSERVATORIES ,CHINESE ACADEMY OF SCIENCES

MONASH University

MODEST-13, Almaty 20/8/2013

Overview

- Galactic globular cluster system
- Stability boundary inside a cluster beyond which stars are unstable to escape from the cluster
- Application to velocity dispersion observations for the Milky Way GC system
- Comparison between the stability boundary method (based on Newtonian dynamics) and MOND in the context of flattening of velocity dispersions

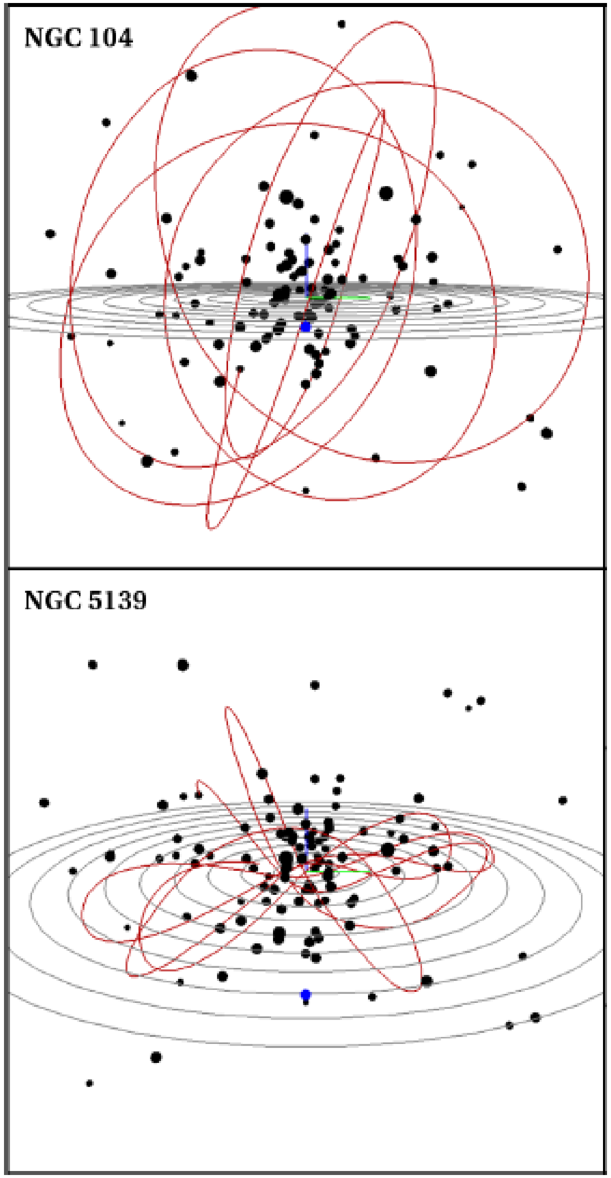
- **Based on astroph: 1108.5241 and 1108.5242**

Globular cluster orbits

- Globular clusters are not isolated systems
- The Galaxy has an effect, even if they are not being actively tidally disrupted
- To investigate other effects I looked at the orbits of 8 GCs with observed velocity components (and published velocity dispersions vs. radius)
- GC-galaxy orbits were determined from these and approximated by Keplerian orbital elements so that a 3-body stability analysis could be applied

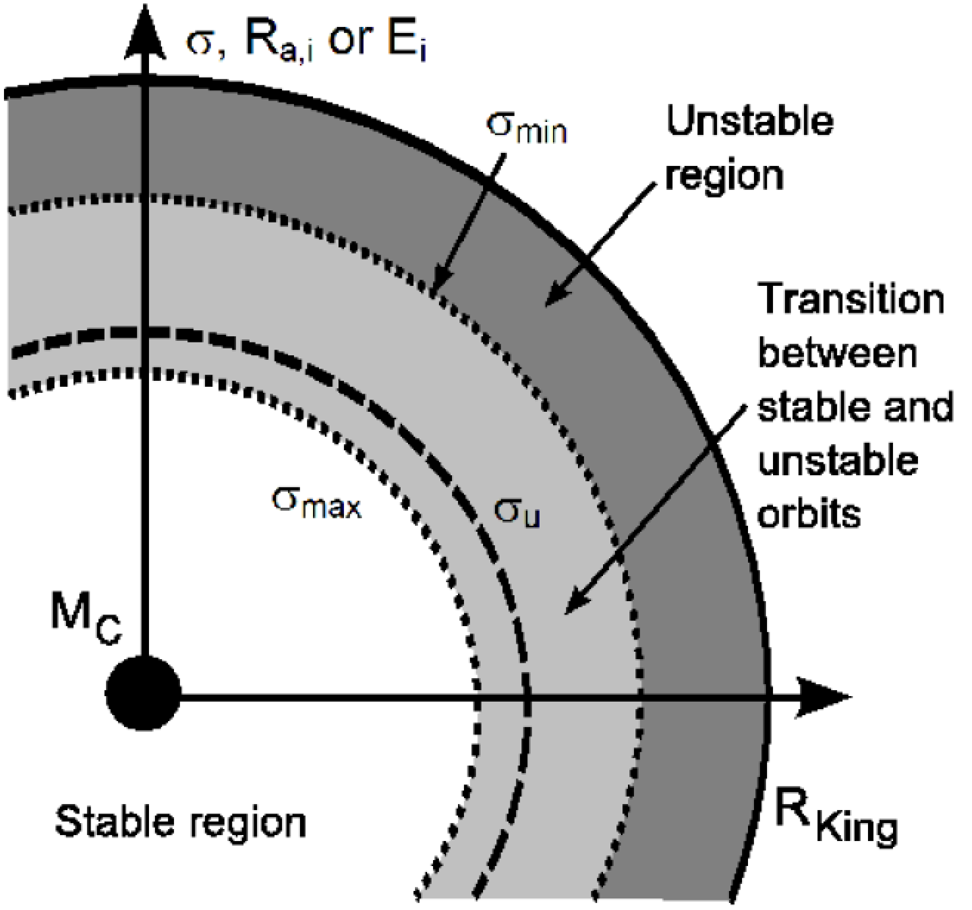
Galactic Globular Cluster System

- Galactic potential of Fellhauer et al. 2007 is used and the cluster orbits are integrated back in time
- Physical positions and velocities from observations, but subject to large uncertainties in tangential velocity and distances
- Minimum/maximum distances from calculated orbit are used to determine peri/apogalacticon
- Use observational errors to generate multiple (10^3) positions and velocities for each GC



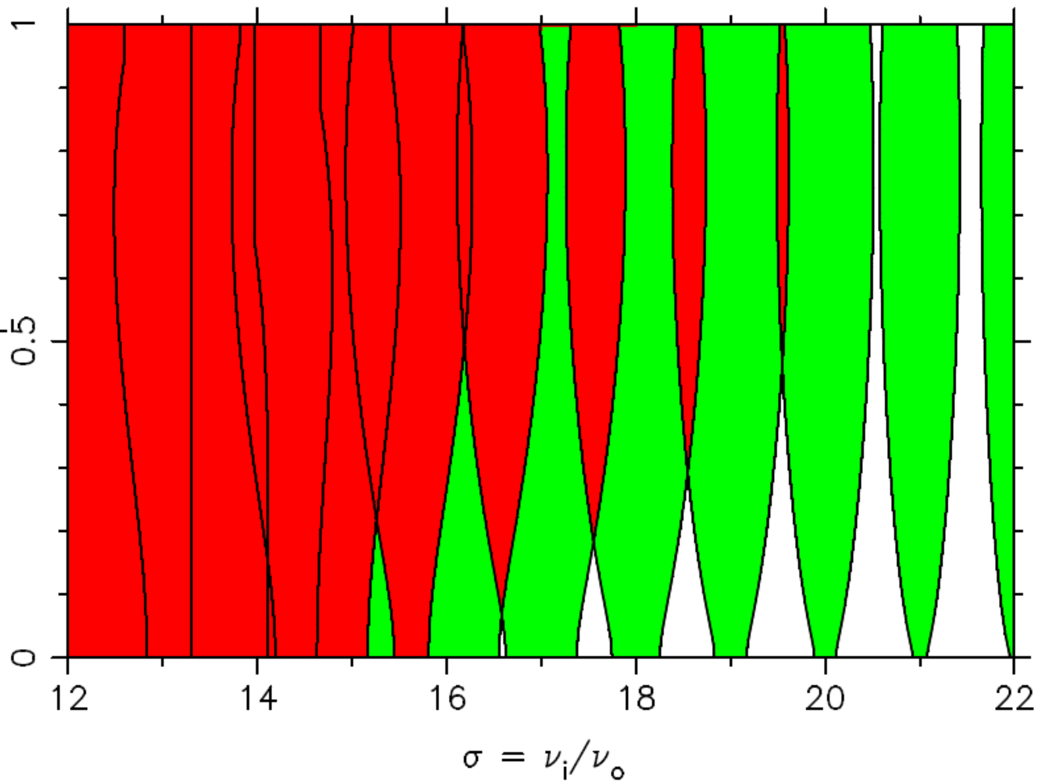
Stability boundary

- Wish to find a radius such that all stars on exterior orbits will be unstable to escape from the cluster
- Will use the stability of the general three-body problem to determine this by treating the star, cluster and galaxy as point-mass particles
- Stability boundary given by averaging over star-cluster orbits



Calculating the stability boundary

- Use Rosemary Mardling's stability criterion with additional terms for inclined orbits
- System is predicted to be unstable if two adjacent resonances (green) with a period ratio of n:1 overlap (red)



- In the context of a star-cluster centre-galaxy system then unstable means that the star will ***eventually*** escape the system
- Timescale of approx. 10 GC-galaxy orbits

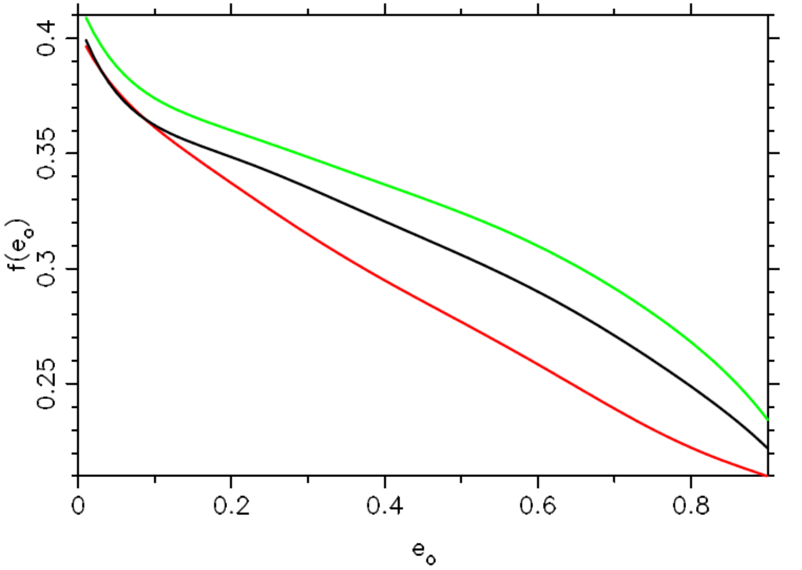
Dependence on eccentricity

- Write the stability boundary in the form

$$r_t = R_p \left(\frac{M_C}{M_G}\right)^{1/3} f(e)$$

where R_p is the perigalacticon, M_C is the cluster mass and M_G is the mass of the galaxy particle.

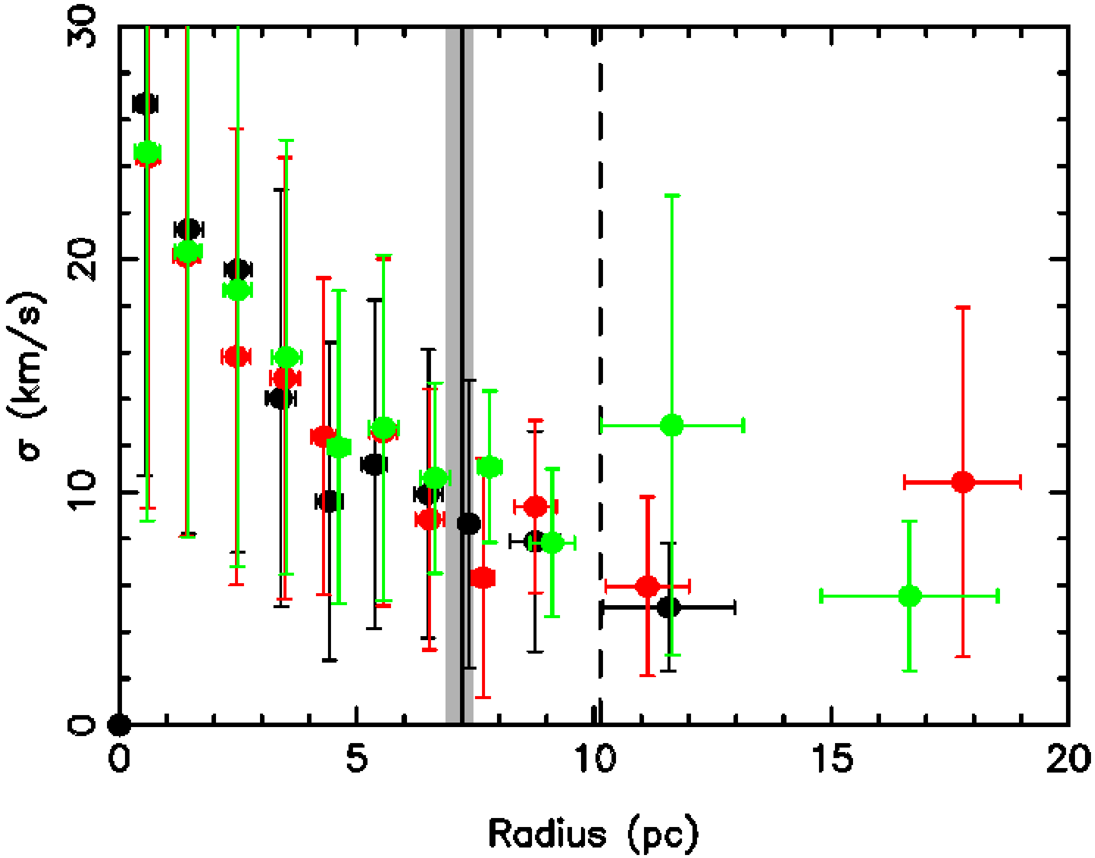
- The dependence of f(e) on the cluster-galaxy orbital eccentricity is shown to the right. The curves show the min/max and r_{chaos} values



- Tidal radius (King 1962) is: $f(e) = 0.7\ (3 + e)^{-1/3}$ which varies from 0.48 to 0.44 at e = 0.9

Effect of unstable orbits

Results from a simple cluster model built and used to investigate the effect of particles on unstable orbits on the velocity dispersion



Velocity dispersion profile after 10 (black), 20 (red) and 30 (green) cluster-galaxy orbits is shown. The transition from stable inner to unstable outer orbits is shaded and the indicative radius (r_{chaos}) is shown as a vertical line. The dashed line shows the King radius.

Velocity dispersions

- Equilibrium model based on Newtonian dynamics

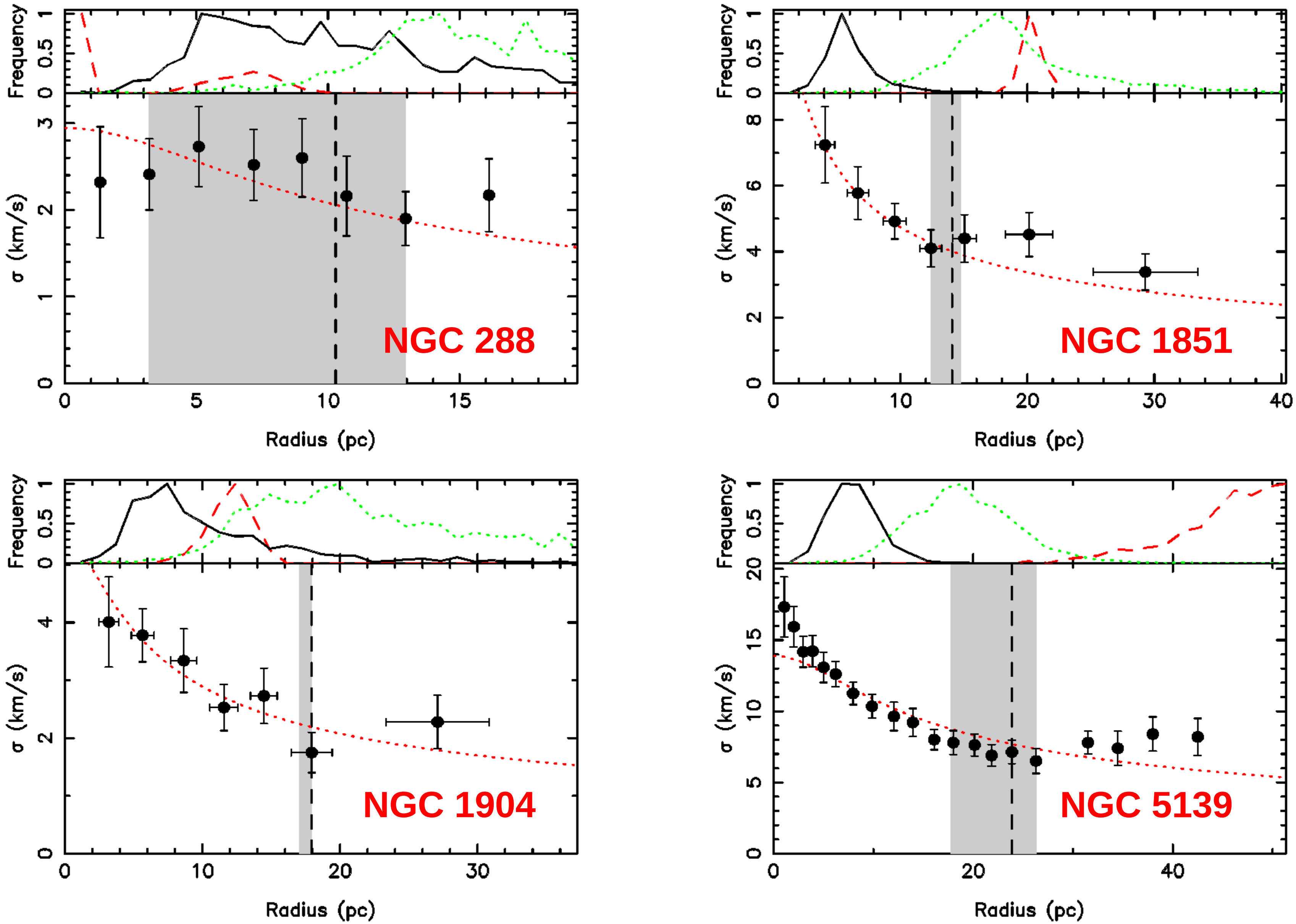
$$\sigma^2(R) = \frac{\sigma_0^2}{\sqrt{1+\frac{r^2}{r_{1/2}^2}}} \quad \text{where} \quad M_C = \frac{64\sigma_0^2 r_{1/2}}{3\pi G}$$

  links the cluster mass with the central σ
- Observations of flattening velocity dispersion at large distances from the cluster centre
- Possible explanations:
  - Tidal interactions with the galaxy
  - Breakdown of Newtonian dynamics
  - **Chaotic orbits in outer regions**

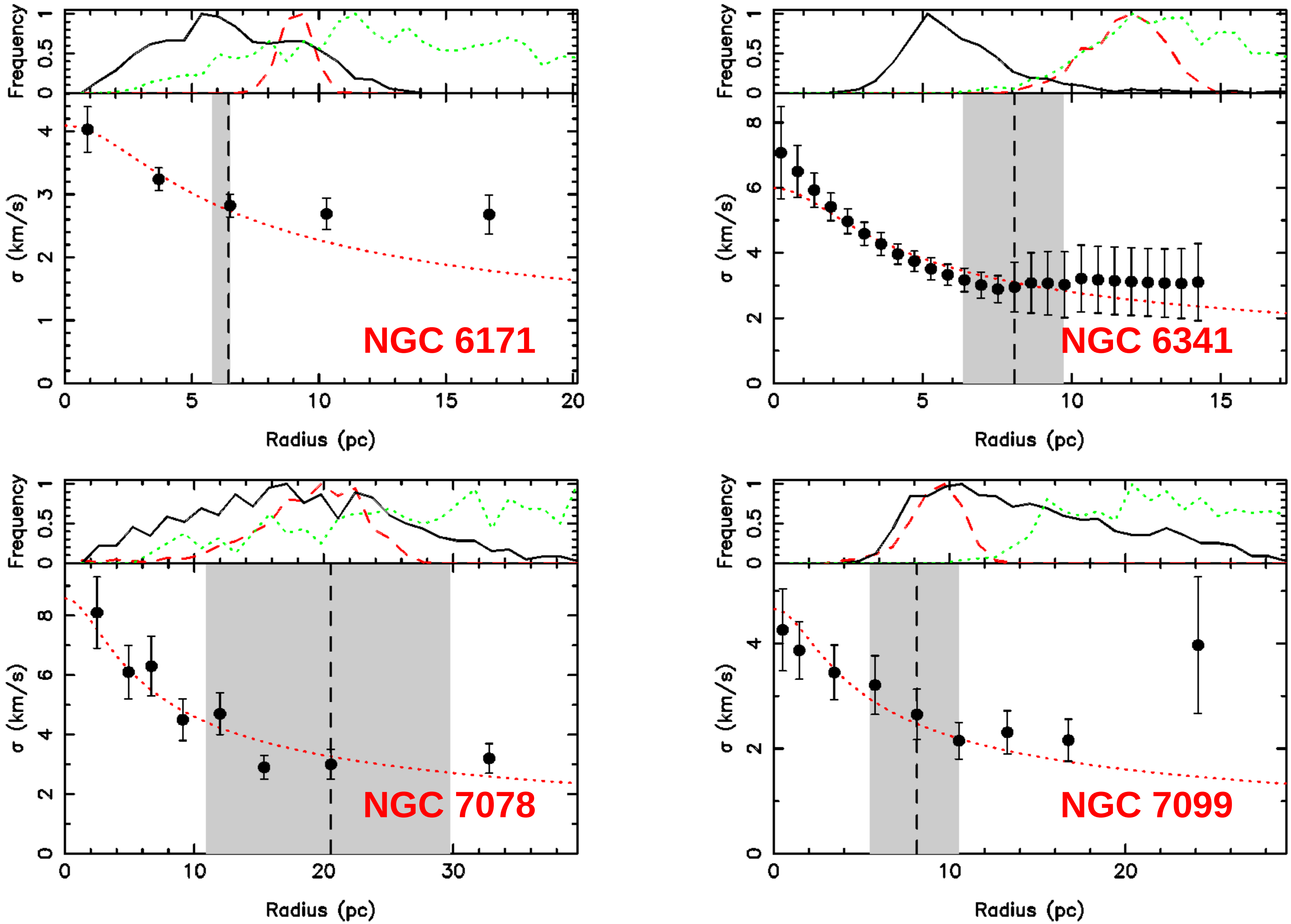
Velocity dispersions

- 8 clusters have been chosen with good radial coverage of the velocity dispersion and with all of the cluster velocity components published
- In all figures:
  - Observational data points and errors from literature
  - Red dotted curves give the Newtonian equilibrium velocity dispersion
  - Vertical red dashed lines show the radius for MOND acceleration
  - Solid black vertical line shows the stability boundary (r_{chaos})
  - Green dotted line shows the tidal radius
  - Shaded region shows the best fit to the flattening radius
- A fit to the central velocity dispersion (where it is Newtonian) is used to determine the cluster mass

Velocity dispersions



Velocity dispersions



Results summary

Cluster	M_C	R_P (kpc)	e	$r_{1/2}$ (pc)	r_c (pc)	r_{a0} (pc)	r_t (pc)	Model
NGC 288	$0.8^{+0.2}_{-0.2}$	$3.8^{+2.9}_{-1.5}$	$0.5^{+0.1}_{-0.2}$	5.8	$10.6^{+10.0}_{-4.7}$	$5.2^{+2.4}_{-5.2}$	$23.0^{+18.3}_{-9.2}$	C
NGC 1851	$3.6^{+0.2}_{-0.2}$	$1.9^{+0.7}_{-0.4}$	$1.0^{+0.0}_{-0.0}$	1.8	$5.7^{+2.2}_{-1.3}$	$20.4^{+0.6}_{-0.7}$	$18.1^{+6.4}_{-3.9}$	T
NGC 1904	$1.4^{+0.3}_{-0.3}$	$3.2^{+2.3}_{-1.1}$	$0.8^{+0.0}_{-0.1}$	3.0	$8.6^{+7.4}_{-3.2}$	$12.2^{+1.3}_{-1.7}$	$22.3^{+16.2}_{-7.7}$	T
NGC 5139	$23.5^{+6.2}_{-6.8}$	$1.0^{+0.3}_{-0.3}$	$0.7^{+0.1}_{-0.1}$	7.7	$7.9^{+2.5}_{-2.3}$	$51.3^{+6.4}_{-7.8}$	$18.9^{+5.1}_{-4.9}$	T
NGC 6171	$0.9^{+0.1}_{-0.1}$	$2.0^{+0.8}_{-0.7}$	$0.3^{+0.2}_{-0.2}$	3.2	$6.4^{+3.2}_{-2.7}$	$9.1^{+0.5}_{-0.6}$	$12.7^{+5.5}_{-4.8}$	C
NGC 6341	$1.3^{+0.2}_{-0.2}$	$2.0^{+0.6}_{-0.4}$	$0.7^{+0.1}_{-0.1}$	2.2	$5.9^{+2.2}_{-1.3}$	$11.9^{+1.2}_{-1.4}$	$13.9^{+4.6}_{-2.8}$	C
NGC 7078	$3.5^{+1.2}_{-1.4}$	$5.4^{+2.1}_{-2.3}$	$0.9^{+0.0}_{-0.1}$	3.0	$17.7^{+8.5}_{-8.0}$	$19.5^{+3.4}_{-4.8}$	$48.6^{+22.0}_{-22.0}$	M
NGC 7099	$0.8^{+0.2}_{-0.2}$	$4.3^{+2.0}_{-1.3}$	$0.3^{+0.1}_{-0.1}$	2.4	$13.7^{+7.4}_{-4.8}$	$9.3^{+1.3}_{-1.6}$	$27.0^{+13.3}_{-8.6}$	M

- Massive observational uncertainties in the orbit; not included are the 10% distance errors, which effect $r_{1/2}$
- Preferred model (col 9) is calculated by the fraction of r_x < the best fit r_{flat} where **C = chaos, T = tidal and M = MOND**
- NGC 7078 and 7099 are core collapsed clusters

Conclusions

- **Flattening of the velocity dispersion of globular clusters is predicted to occur beyond a certain radius by consideration of three-body stability in Newtonian dynamics**
- This occurs in the outer regions of a cluster where two-body relaxation is (generally) negligible and in clusters which are not being strongly tidally disrupted
- **Predicted radius depends on the GC-galaxy orbit and not just on the cluster mass, which provides a way of distinguishing these predictions from MOND models**
- Additional observations of GC proper motions will provide a strong test for both of these models
- **Currently running n-body simulations to closer examine the effect in realistic galactic potentials**

References

- A = Drukier et al. (1998)
- B = Scarpa et al. (2003)
- C = Scarpa et al. (2004)
- D = Drukier et al. (2007)
- E = Scarpa et al. (2007a)
- F = Scarpa et al. (2007b)
- G = Scarpa & Falomo (2010)
- H = Scarpa et al. (2011)
- 1 = Meziane & Colin (1996) and references therein
- 2 = Dinescu et al. (1999) and references therein
- 3 = Dinescu et al. (2001)
- Fellhauer et al. (2007) MNRAS 380, 749–756
- Mardling R. A., 2008, in Aarseth S. J., Tout C. A., Mardling R. A., eds, Lecture Notes in Physics, Vol. 760: The Cambridge N-body Lectures Resonance, chaos and stability: the three-body problem in astrophysics
- **For more info see: astroph 1108.5241 and 1108.5242**