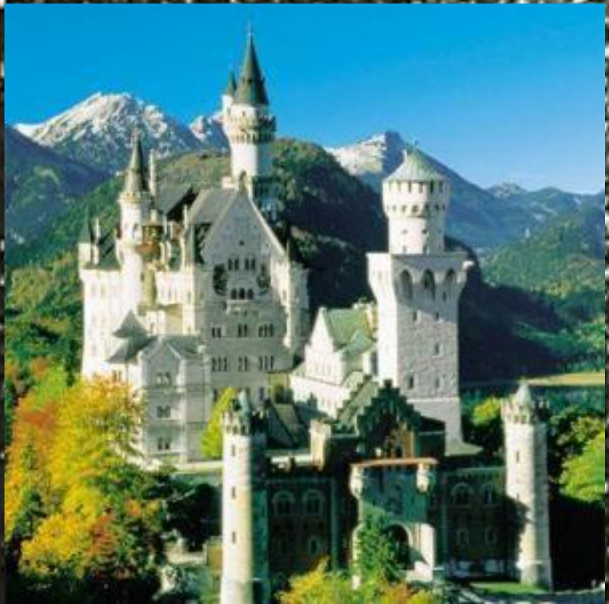
Globular Cluster-Massive Black Hole Interaction in Galactic Centers



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R. Capuzzo Dolcetta

3 Junel 2014

Thanks to Pavel and Sambaran for the invitation.

Some former and present collaborators:
F. Anntonini, M. Arca Sedda, A. Mastrobuono Battisti,
D. Merritt, P. Miocchi, M. Spera,

Thanks also S. Mikkola for discussions.

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host
2500 euros

4 GPUs
1200 euros

Speed 16TFlops

Power: 1.5 KW

Cost: 3700 euros

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Massive 'compact objects' in galactic centers

SMBHs - MBHs - resolved stellar nuclei - NSCs

($10^6 \div 10^{10} M_\odot$) ($10^5 \div 10^8 M_\odot$)

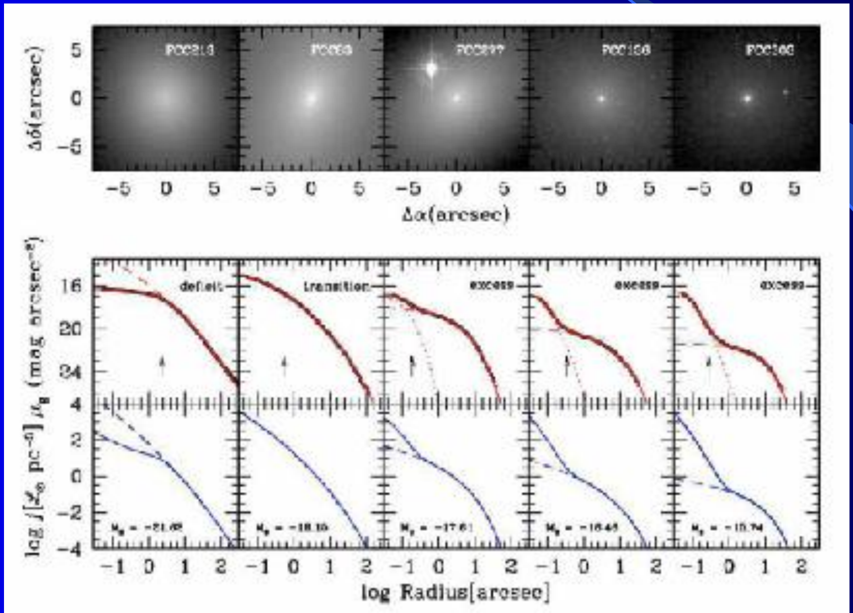
decreasing host galaxy luminosity →

increasung steepness of the lum. profile →

Brighter galaxies host more massive and compact objects

Fainter galaxies have more peaked luminosity distribution

Resolved stellar Nuclei found in galaxies fainter than $M_B = -19.5$



Decreasing luminosity →

ACSFCS sample (Turner et al. 2012)

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• The MW and a handful of other galaxies are also known to contain **both** an NSC and an MBH (Seth et al. 2008a, Graham & Driver 2007, Graham & Spitler 2009), and the ratio of MBH to NSC mass in these galaxies is of order unity.

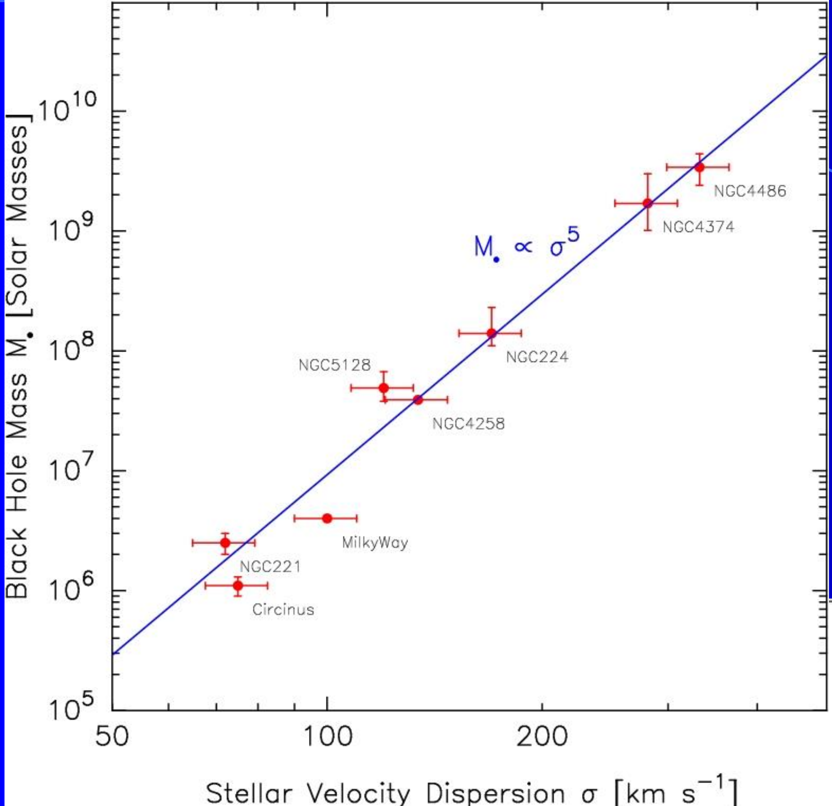
• In models of NSCs, the dynamical influence of a MBH should therefore be **considered**, at least in bulges brighter than about $10^9 L_\odot$ *which are believed to always contain* an MBH (Ferrarese & Ford 2005).

How do NSCs form?

Two competing models hve been proposed so far:

- The *gas model* : gas migrates to the center of the galaxy where then forms stars (Schinnerer et al. 2006, 2008).

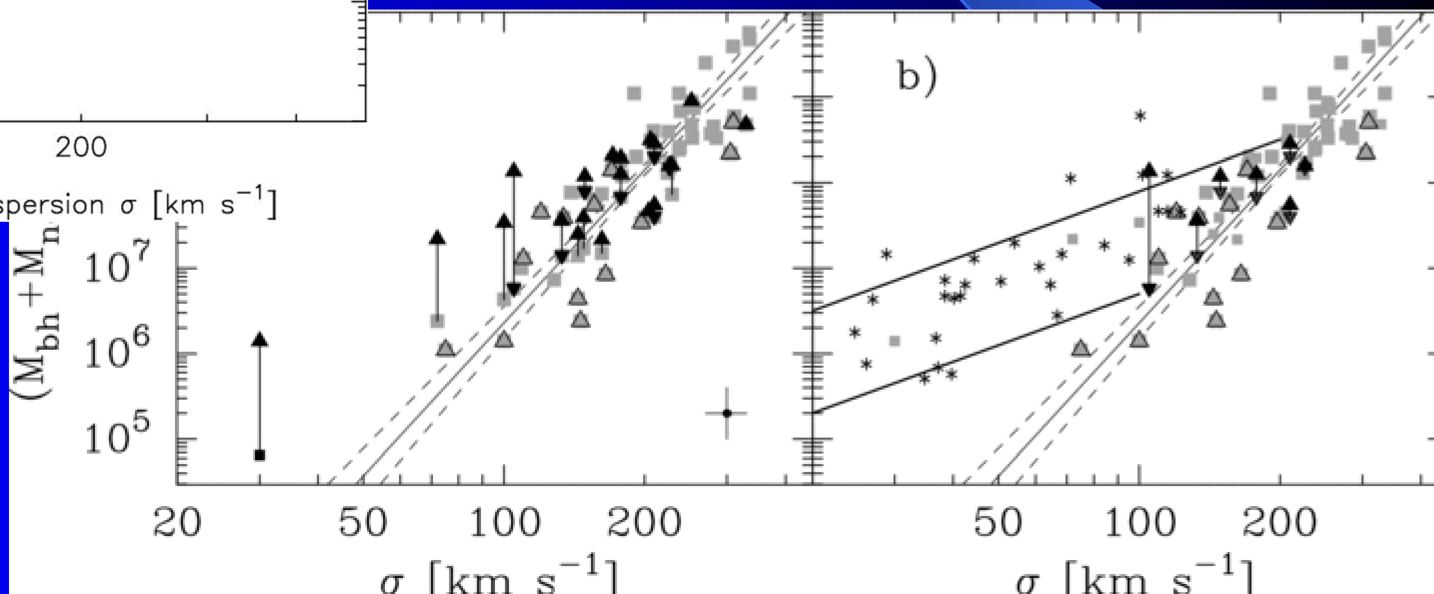
- The dry *merger model*: massive clusters migrate to the center via dynamical friction and merge to form a dense nucleus (Tremaine et al. 1975, Ostriker 1988, Capuzzo-Dolcetta 1993, Miocchi & Capuzzo-Dolcetta 2008, Agarwal & Milosavljevic 2011).



mass vs σ relation

$M_{BH} \propto \sigma^5$

$M_{NSC} \propto \sigma^{1.6}$



Graham 2012, 422, 1586

$$\text{Log}\frac{M_{NSC}}{M_\odot} = (1.57 \pm 0.24)\ \text{Log}\frac{\sigma}{70km/sec} + 6.83 \pm 0.07$$

A simple interpretation of the NSC M vs σ scaling law

Hypothesis: singular isothermal sphere

$$\rho(r) = \frac{1}{2\pi G}\frac{\sigma^2}{r^2},$$
$$M(r) = \frac{2\sigma^2}{G} r,$$
$$v_c^2 = 2\sigma^2.$$

The GC orbital evolution due to dynamical friction is governed by

$$\frac{dL}{dt} = \sqrt{2}\sigma\dot{r} = r\ddot{r}_{df} = -0.4276\frac{GM\ln\Lambda}{r}$$

$$r^2(t) = r^2(0) - 0.6047 GM\ln\Lambda\frac{t}{\sigma}$$
$$\Downarrow$$
$$M_n(t) = \frac{2\alpha}{G}\sigma^2 r(t_0) = \frac{2\alpha}{G} A t^{1/2}\sigma^{3/2}$$

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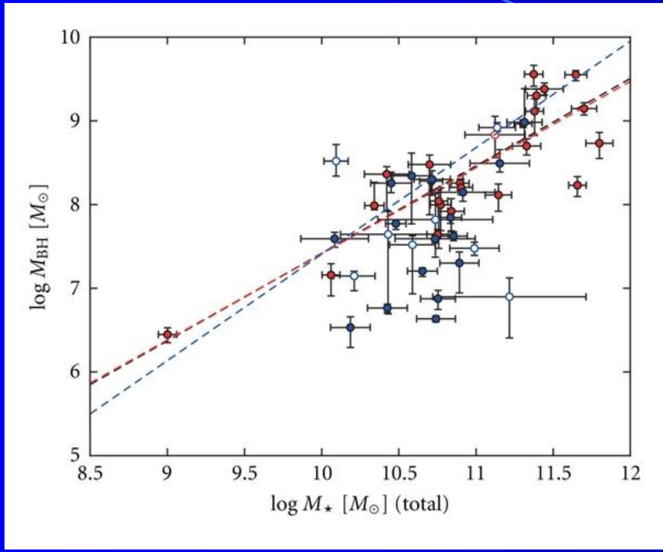
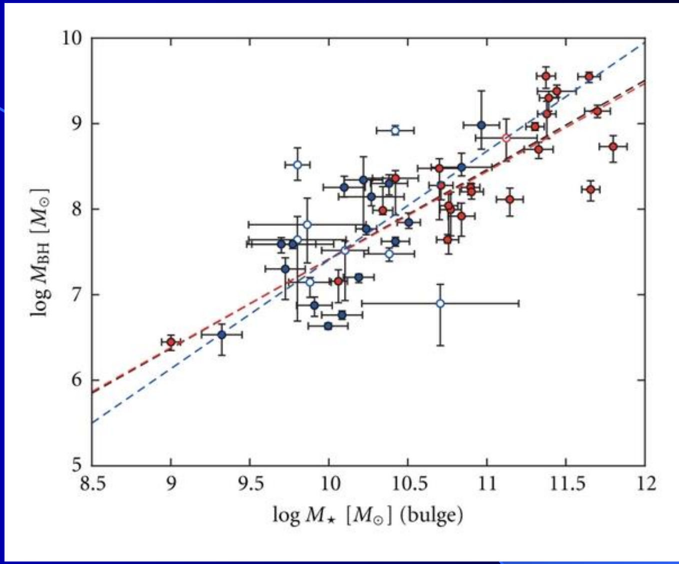
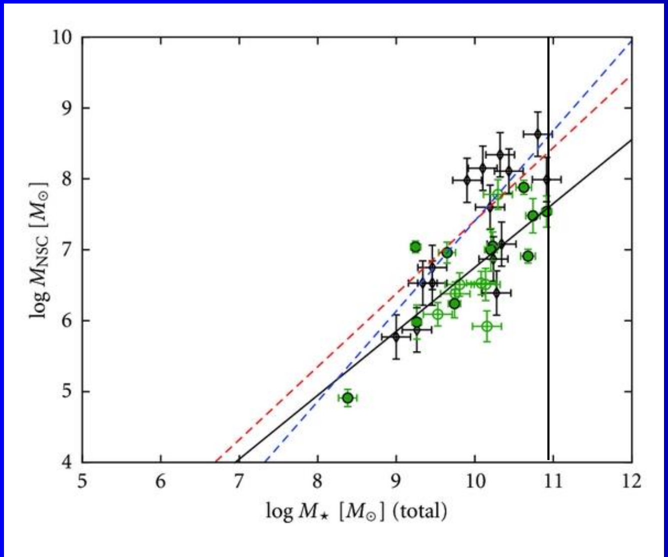
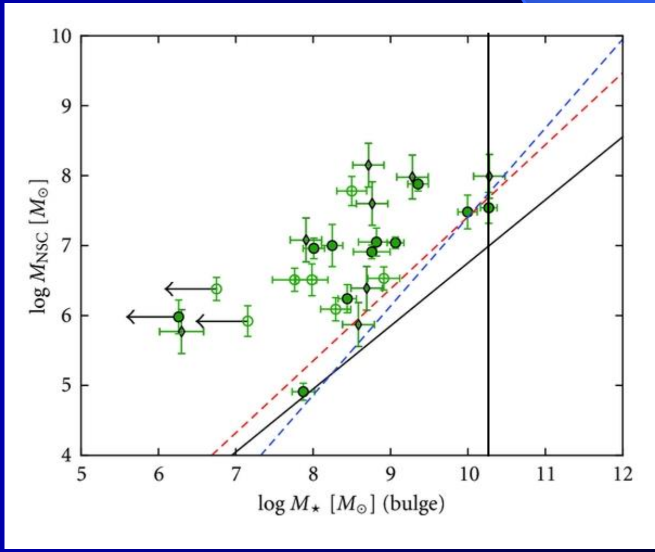
BHs





NSCs





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Some simulations …

Ingredients

- **Host galaxy**: represented by a self-consistent particle model; contains a **massive** BH.
- **The GCs**: massive GCs evolved up to a King quasi-equilibrium profile, initially located at close distance from the galactic center.

Computations:

Done with **PhiGRape**, **NBSymple and HiGPUs**, high-precision, direct sum, parallel codes running on composite CPU+GPU systems.

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MBH-GC

movingBH

simultaneousmerger

consecutivemerger

SMBH

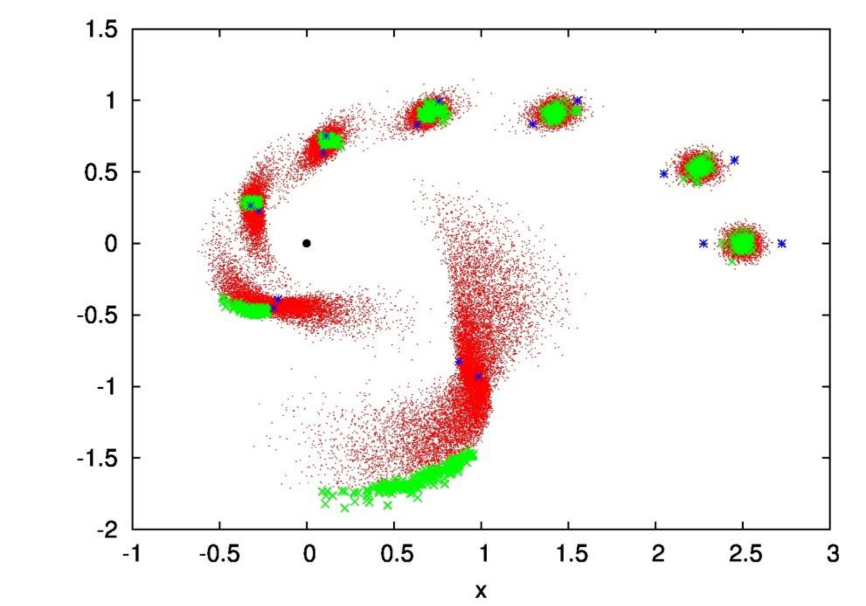
MBH

High velocity stars from a GC

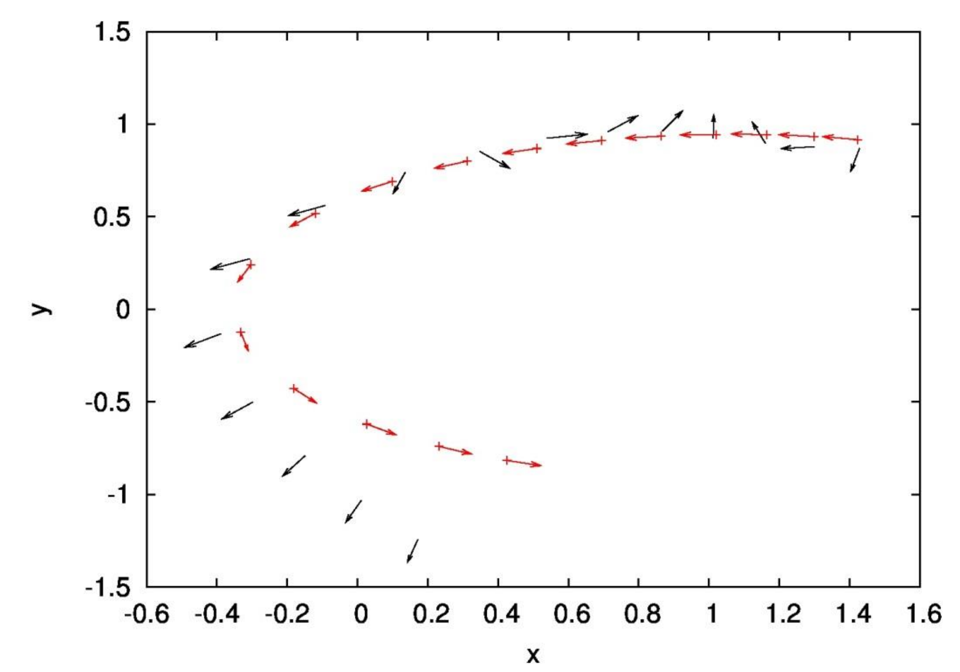
High velocity stars from a compact GC

High velocity stars from a GC

High velocity stars from a compact GC



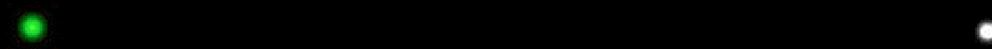
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-1
-0.5
0
0.5
1
1.5
2
2.5
3
x



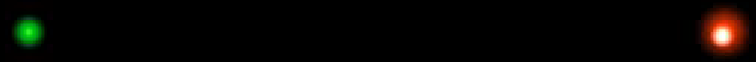
1.5
1
0.5
0
-0.5
-1
-1.5
y
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
x

Regularized 3 body integrations

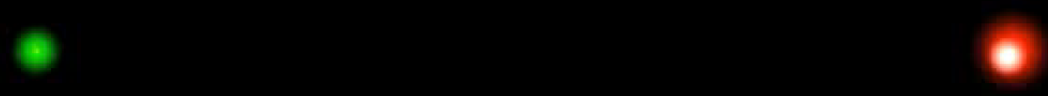
Immediate ejection



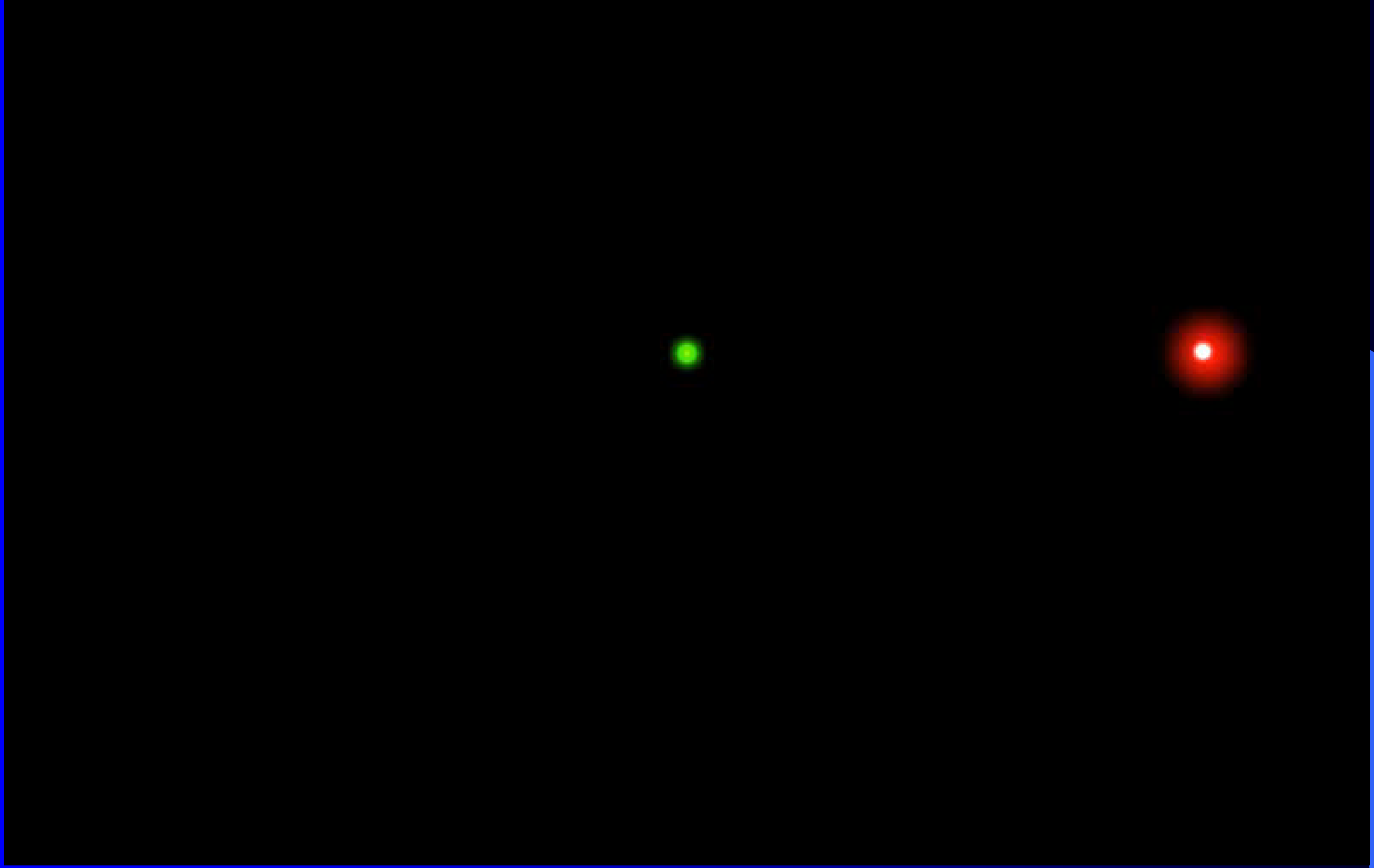
Delayed ejection



Release to the MBH and ejecton



Release to and recapture from MBH



Conclusions

What we found:

In galaxies with $M_g > 5 \times 10^{10} M_\odot$ ($M_{SMBH} > 5 \times 10^8 M_\odot$) SMBH tidal forces are strong enough to disrupt most of the incoming clusters, preventing the formation of a nucleated region within the galactic center.

Clusters which move on eccentric orbits lose a population of stars that are ejected from the galaxy at high velocities. This can be a complementary mechanism to explain the origin of High-Velocity Stars are observed in galactic haloes.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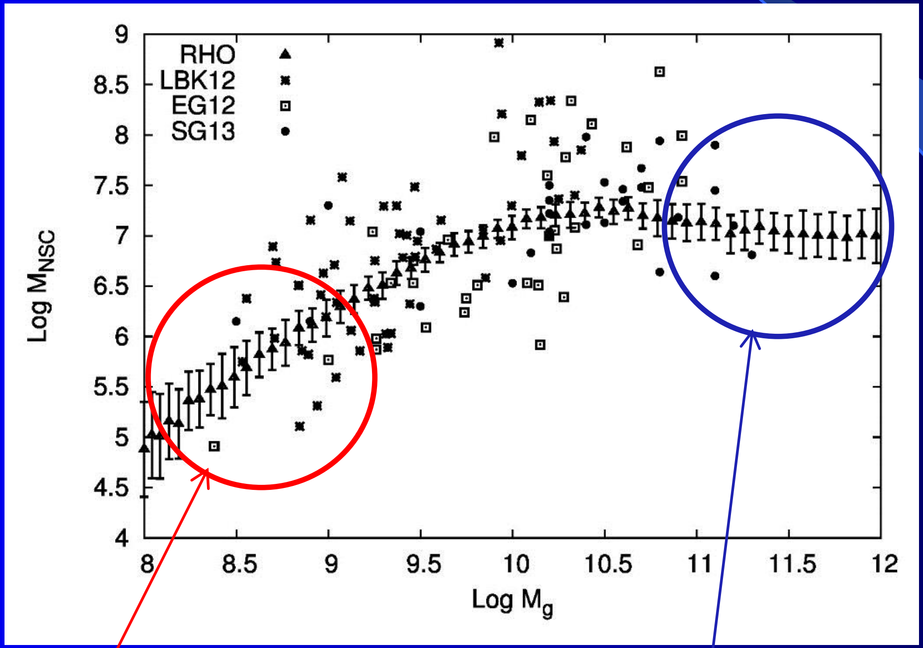
Thanks for the attention

How do Nuclear Clusters form?

The dry merger model



[3] Leigh et al., 2012, MNRAS, 424,2130

- ✓ The dynamical friction (df) process drags stellar clusters toward the galactic center
- ✓ The tidal heating (th) process disrupt the in falling stellar clusters

Dynamical friction dominates

Tidal heating dominates

from Arca Sedda & Capuzzo Docetta, 2014, submitted to MNRAS)

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• **Resolved stellar nuclei**

in faint ellipticals: ACS Virgo (Cote' et al. 2004) and Fornax (Jordan et al. 2007) Cluster Surveys.

frequency of nucleation: 66% Virgo, 72% Fornax
less than 10% of nuclei are offset for 0.5"

It is argued that they are the **low-mass counterparts** of nuclei hosting **SBHs** detected in bright galaxies.

• **Nuclear clusters**

in late-type spiral galaxies (Böker 2008): superdense systems with mass in the range $10^5 \div 10^8\ M_\odot$. They reveals a close match in terms of size, luminosity, and overall frequency (but the latter have a young component).

• Global -to- nucleus scaling relations do exist : this imply a link among *large* (galaxy) and *small* (nuclear environment) space-time scales (Capuzzo-Dolcetta 1993; Rossa et al. 2006, etc.).