

# Intermediate Mass Black Holes in Globular Clusters

Is NGC 6535 a dark cluster harbouring an IMBH?

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# Outline

1 Introduction

2 Method

3 The simulation model

4 Mock observation

5 Conclusions



# Aims of the research

- The BH mass range between stellar BHs and SMBHs is still elusive ( $10^2$ - $10^5$   $M_\odot$ )
- **Extrapolation** from  $M_{BH}-\sigma$  relation suggests the possibility of these objects in globular clusters (GCs).
- **Dynamical process** in star cluster (Giersz et al. 2015).
- How can we probe these BHs?



# Strategy

- MOCCA: simulate a lot of GCs with a **wide range of parameters**.
- A fraction of them developed an IMBH  $\Longrightarrow$  **Dark Star Cluster (DSC)**.
- Compare the most representative one with real GCs.
- COCOA: simulate **photometric observation** to compare with real data.
- SISCO: simulate **kinematics observation** to compare with real data.



- Simulation code for long-term evolution of GCs.
- Assumptions: Spherical symmetry, evolution driven by 2-body relaxation.
- Tested against N-body simulations.
- Really fast ( $\sim$  day for  $N \sim 10^6$ ).
- Lot of models with different initial conditions.

# COCOA: Cluster simulatiOn Comparison with ObservAtions



- MOCCA Output: Grid of **physical parameters**: positions, velocities, stellar parameters , magnitudes...
- Projects MOCCA data on to the plane of the sky.
- Simulate an observation for given **instrumental specifications** ( $t_{exp}$ , Field of View, resolution) to recreate any telescope.
- Output: A FITS file (observational data).



- Assigns to every star a **stellar spectrum** based on stellar parameters (from MOCCA)
- Simulate **spectrographic observations** for given instrumental setup (Field Of View, PSF shape, seeing conditions)
- Output: A **3D data cube** with position, spectrum and luminosity information (from COCOA).



# Cluster models

- MOCCA Survey I: 344/1948 models with an IMBH ( $M > 150M_{\odot}$ ) within 12 Gyr.
- 42/344 models with an IMBH mass greater than 50% of cluster mass after 12 Gyr  $\implies$  **Dark cluster harbouring IMBH**.
- Wide range of initial parameters:
  - 1 N from  $4 \times 10^4$  to  $1.2 \times 10^6$ .
  - 2 Metallicity from 0.002 to 0.02
  - 3 Galactocentric radius from 1 kpc to 5 kpc.
  - 4 Binary fraction from 0.05 to 0.95.



# Cluster Evolution

We select a model with initial conditions representative of most dark clusters in the survey.

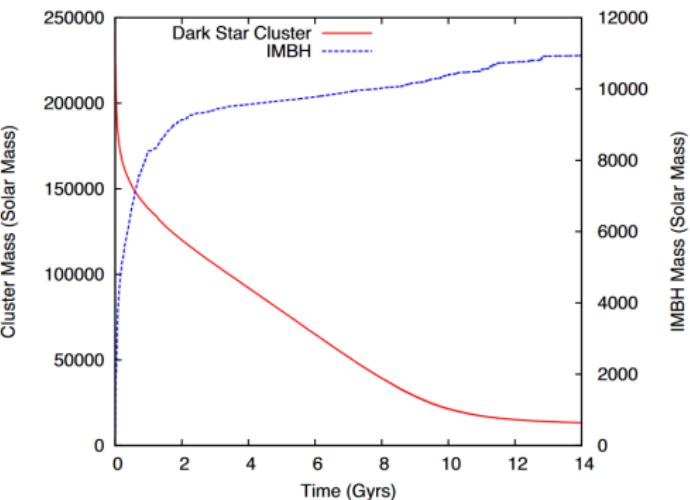
	N	Mass ( $M_{\odot}$ )	Binary fraction	$r_t$ (pc)
Initial	400 000	$2.42 \times 10^5$	10 %	30.0
12 Gyr	8294	$1.51 \times 10^4$	5.8 %	11.92

**Table:** Some of cluster parameters at the start of simulation, then at 12 Gyr.



# Cluster Evolution

- Formation of a massive star ( $M_* = 377 M_\odot$ ) through **collisions of MS stars**.
- Formation of an initial BH ( $195 M_\odot$ ) through **final evolution** of a massive star.
- Collision between star and BH  $\Rightarrow 572 M_\odot$
- Mass of the IMBH grown to 70% of the cluster mass at 12 Gyr.
- Cluster loses mass due to star evolution and tidal stripping.



**Figure:** Cluster and IMBH evolution (Askar et al. 2016)



# Cluster Evolution

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# NGC 6535

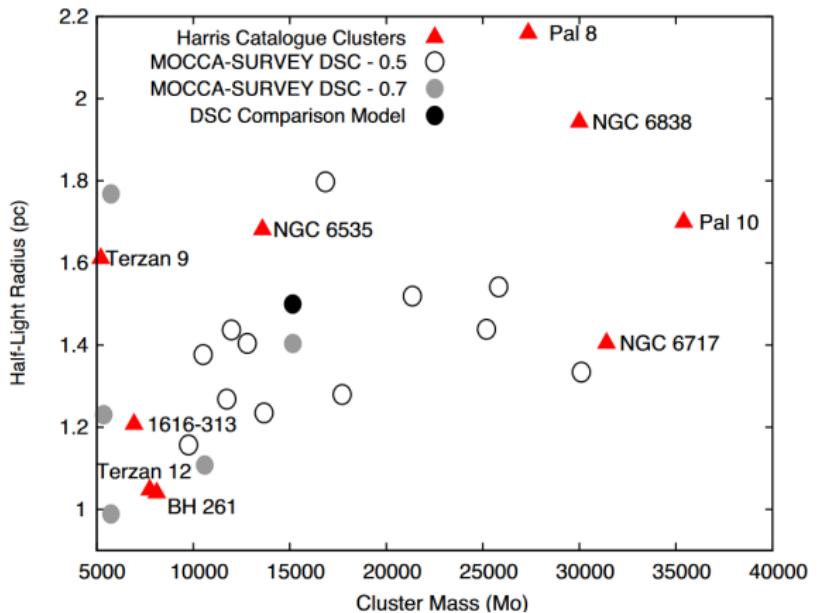


Figure: Harris Catalogue Clusters and MOCCA clusters (Askar et al. 2016)



- NGC 6535 has a M/L ratio value of about  $11 \text{ M}_\odot/\text{L}_\odot$
- Presence of a significant **dark component**.
- Large number of **compact objects** (like stellar BHs) or a **IMBH?**



# Mock Photometry



**Figure:** COCOA mock observation (left panel) and Hubble image of NGC 6535 (right panel)



# Mock Photometry

- With COCOA we can simulate a photometric observation.
- We can compare colour-magnitude diagrams (CMD).
- Small observational differences due to different metallicity.
- Model with different metallicity takes in account these differences ( $Z = 3.24 \times 10^{-4}$ ).
- Same evolution properties of our model at 10.5 Gyr. Same age of NGC 6535 (Marn-Franch et al. 2009).

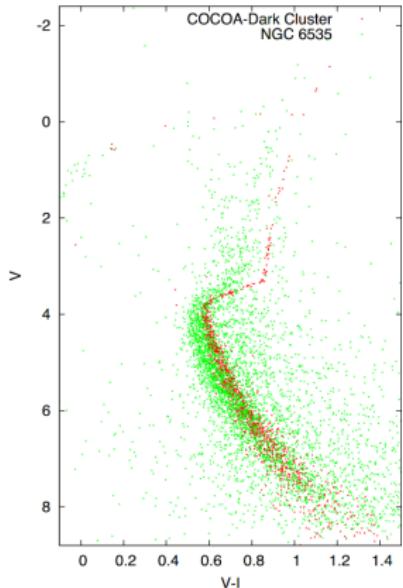


Figure: CMD of NGC 6535 (green points) and our model (red points).



# Mock Kinematics

- We can compare **dispersion velocity profile** from the MOCCA simulation to real observations.
- Problem: **Absence** of data in the **inner** region.
- We can simulate kinematic observations of the **inner region** with SISCO.

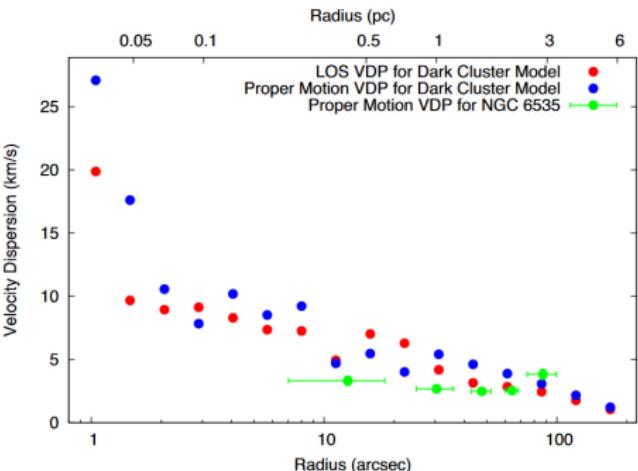
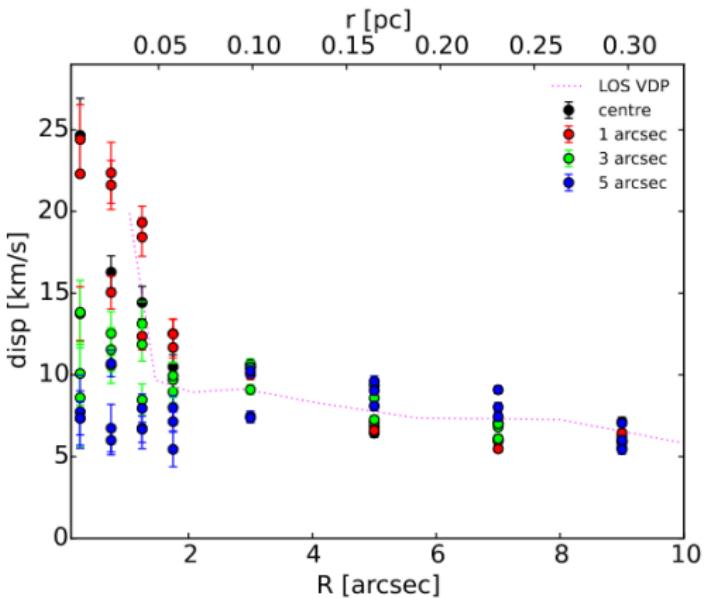


Figure: VDP for simulated cluster and NGC 6535 (Askar et al. 2016)



# Mock Kinematics



**Figure:** IFU velocity dispersion profiles with different centres (Askar et al. 2016)



# Estimate of M/L ratio

- Estimate of M/L ratio from mock observations.
- We can estimate  $M_{1/2} \simeq 930 \left[ \frac{\sigma_{los}^2}{km^2 s^{-2}} \right] \left[ \frac{R_h}{pc} \right] M_\odot$  using  $R_h$  from COCOA and  $\sigma_{los}$  from SISCO.
- We get  $M/L \simeq 17 M_\odot/L_\odot$ .
- Same thing for NGC 6535 from real observations  $\implies M/L \simeq 11.4 M_\odot/L_\odot$
- Large subsystem of compact objects or IMBH?



# Prospect for the future

- Kinematic signature of an IMBH in **small clusters** (like NGC 6535) easier to detect compared to large GCs.
- Future **kinematic observations**: ARGUS at VLT (high spatial sampling and high spectral resolution)
- **N-body simulation** for clusters with these initial conditions.



# References

- *MOCCA-SURVEY Database I: Is NGC 6535 a dark cluster harbouring an IMBH?* (Askar, Bianchini, de Vita, Giersz, Hypki and Kamann 2016)
- *MOCCA code for star cluster simulations IV. A new scenario for intermediate mass black hole formation in globular clusters* (Giersz et al. 2015)