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Unveiling Impacts of Dynamical Effects on the Cataclysmic Variables in Globular Clusters

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Introduction

Globular cluster (GC)

One of the densest object in the universe

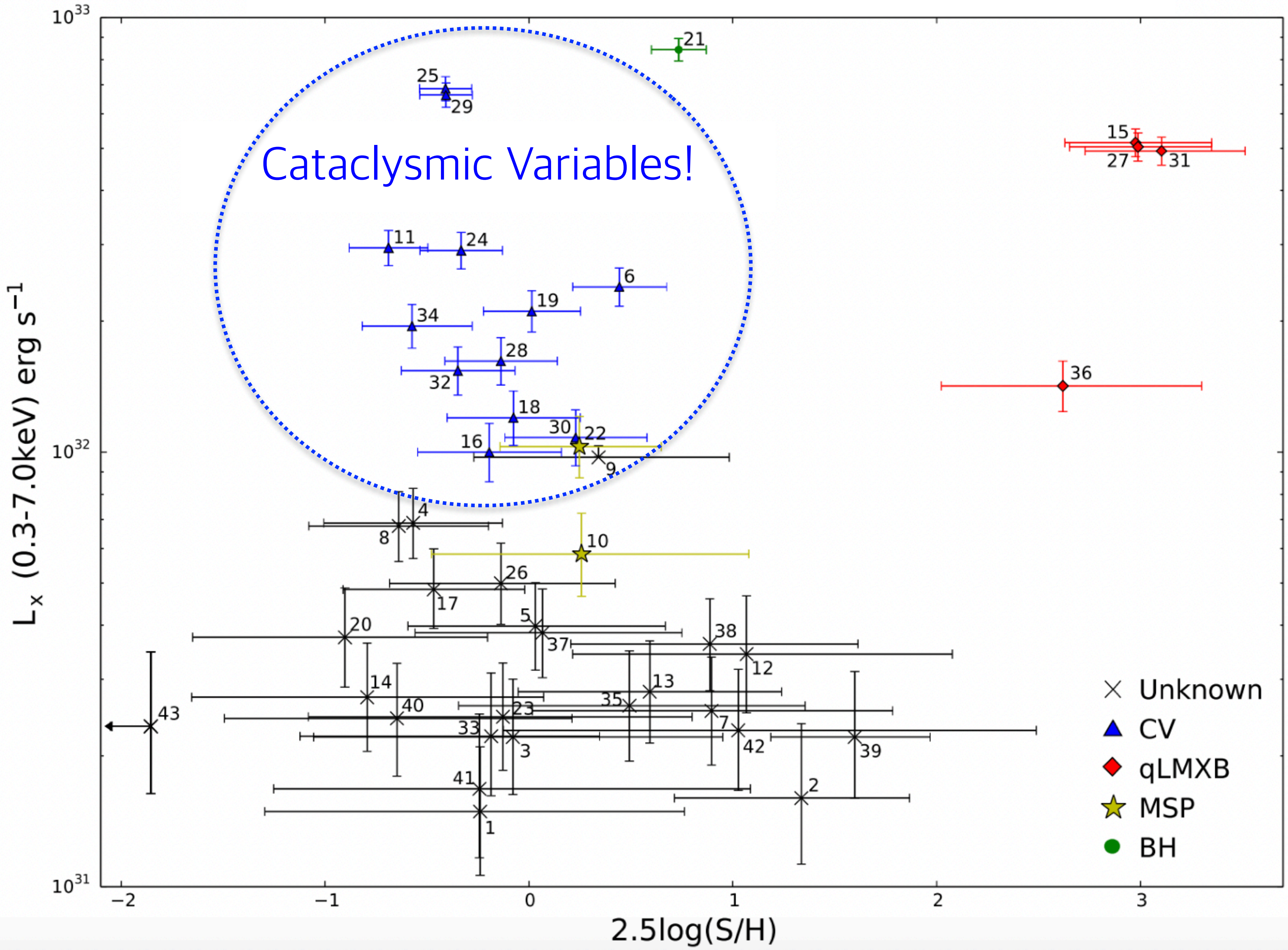
- Strong dynamical interaction (high encounter rate)
- Efficient factory of compact binaries
- ~160 GCs in our galaxy

Why Globular Cluster

- More exotic phenomena than galactic field
- Resources after launching high resolution telescopes
  (e.g. Hubble space telescope, Chandra X-ray observatory)
- Good window for binary formation episodes
- Already well-known distance

Globular cluster (GC)

Colour-Magnitude diagram of M62



K. Oh et al (2021)

Cataclysmic Variable

Cataclysmic Variable (CVs)

What is CV?

- Binary composed of a White Dwarf (WD) and a Main Sequence (MS) star
- Focus on bright CV (e.g. intermediate polar, polar, magnetic CVs)
- Spectrally hard and bright in X-ray

Role of CV formation

- GC is good environment for studying formation of CVs
- Interesting formation origin
- Simulation vs Observation

MOCCA

MOnte Carlo Cluster simulAtor

MOnte Carlo Cluster simulAtor (MOCCA)

What is MOCCA?

- To perform simulations of a real size star clusters
- N-body simulation (up to N=1,000,000)
- Few-body interactions
- Includes detailed evolution of each stars
- Good for studying compact binaries dynamics

How does it work?

- Total 81 models due to the different initial conditions
- Snapshots every 250 Myr
- For the comparison with observation, Present Day Population (PDP), the age around 12 Gyr

MOnte Carlo Cluster simulAtor (MOCCA)

Initial parameters

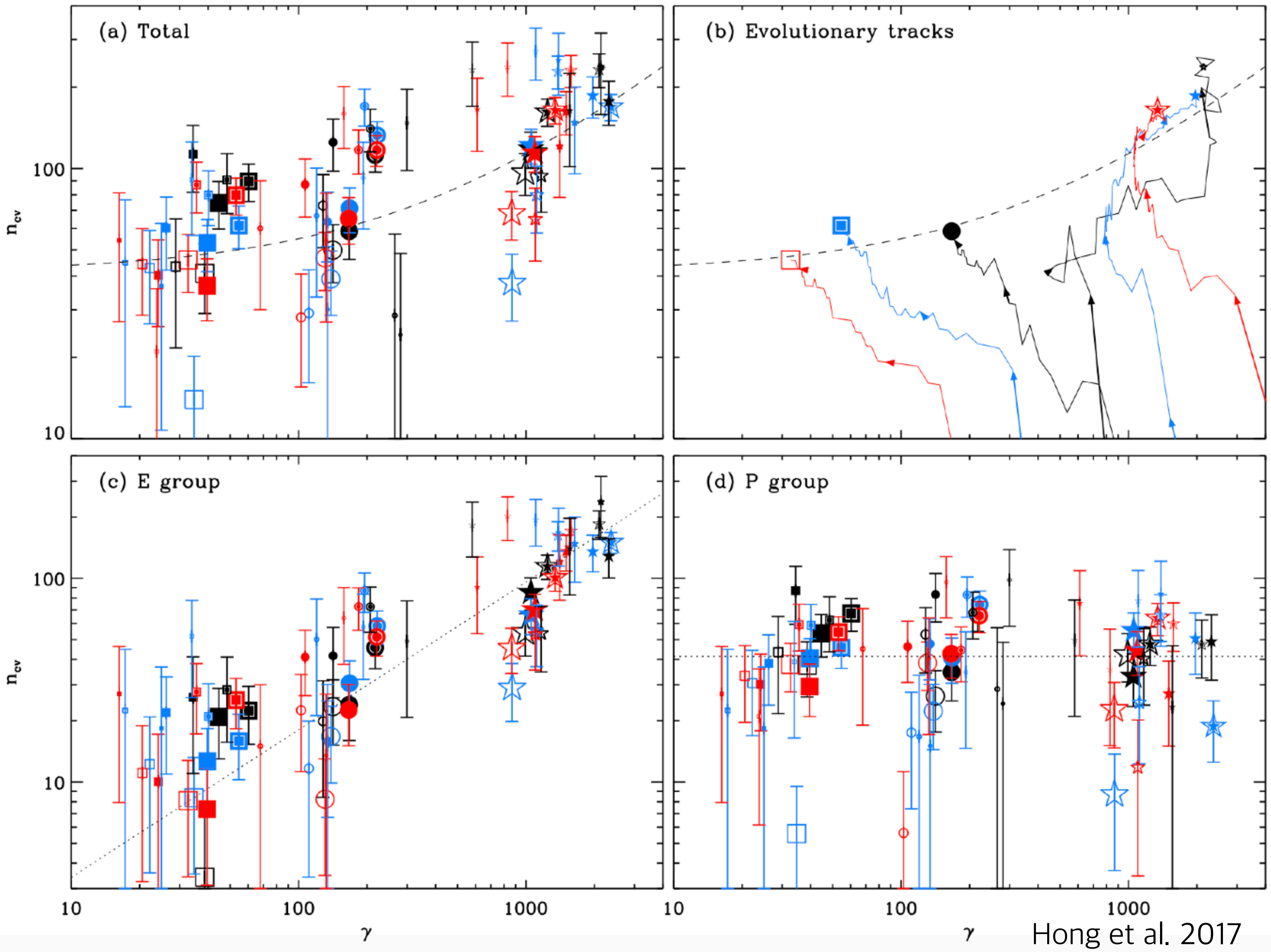
- Initial seed (200K, 500K, 1M)
- Galactocentric distance (4kpc, 8kpc, 16kpc)
- Half-mass radius (1pc, 2pc, 4pc)
- Initial binary fraction (10%, 20%, 50%)

→ Total 81 GC models

Previous work by Hong et al. 2017

- Our study can be the extended study which includes X-ray regime
- CV formation mechanism in GC
- Found the correlation between N_{CV} and encounter rate

Primordial CVs (P group) & Exchange CVs (E group)



Hong et al. 2017

CVs into P group and E group according to their formation origin

Method

Basic procedure

$$q = M_1/M_2, \text{ i.e.}$$

$$\frac{R_{L,1}}{a} = \frac{0.49q^{2/3}}{0.6q^{2/3} + \ln(1 + q^{1/3})}$$

Brief idea before we jump into..

1. CV is comparably easy to classify in X-ray
2. CVs have the large fraction of X-ray emission
3. Can we can derive X-ray luminosity from MOCCA? Yes!
4. Clues for revealing the production dynamics of CVs

Extracting CVs

- Search for the binaries composed of WD and Main sequence (MS)
- Among those binaries, filtering the binaries which have Roche-lobe overflow
- After sorting out, calculate X-ray luminosity

X-ray luminosity of CV (simplified)

Mass transfer rate

- For the CV with cold/neural and stable and unstable disc (Belloni et al. 2016) :

$$\dot{M}_{\rm A} = 6.344 \times 10^{-11}\, \alpha_{\rm c}^{-0.004} \left(\frac{M_{\rm WD}}{\rm M_{\odot}}\right)^{-0.88} \times \left(\frac{r}{10^{10}\ \rm cm}\right)^{2.65} \rm M_{\odot}\ yr^{-1}$$

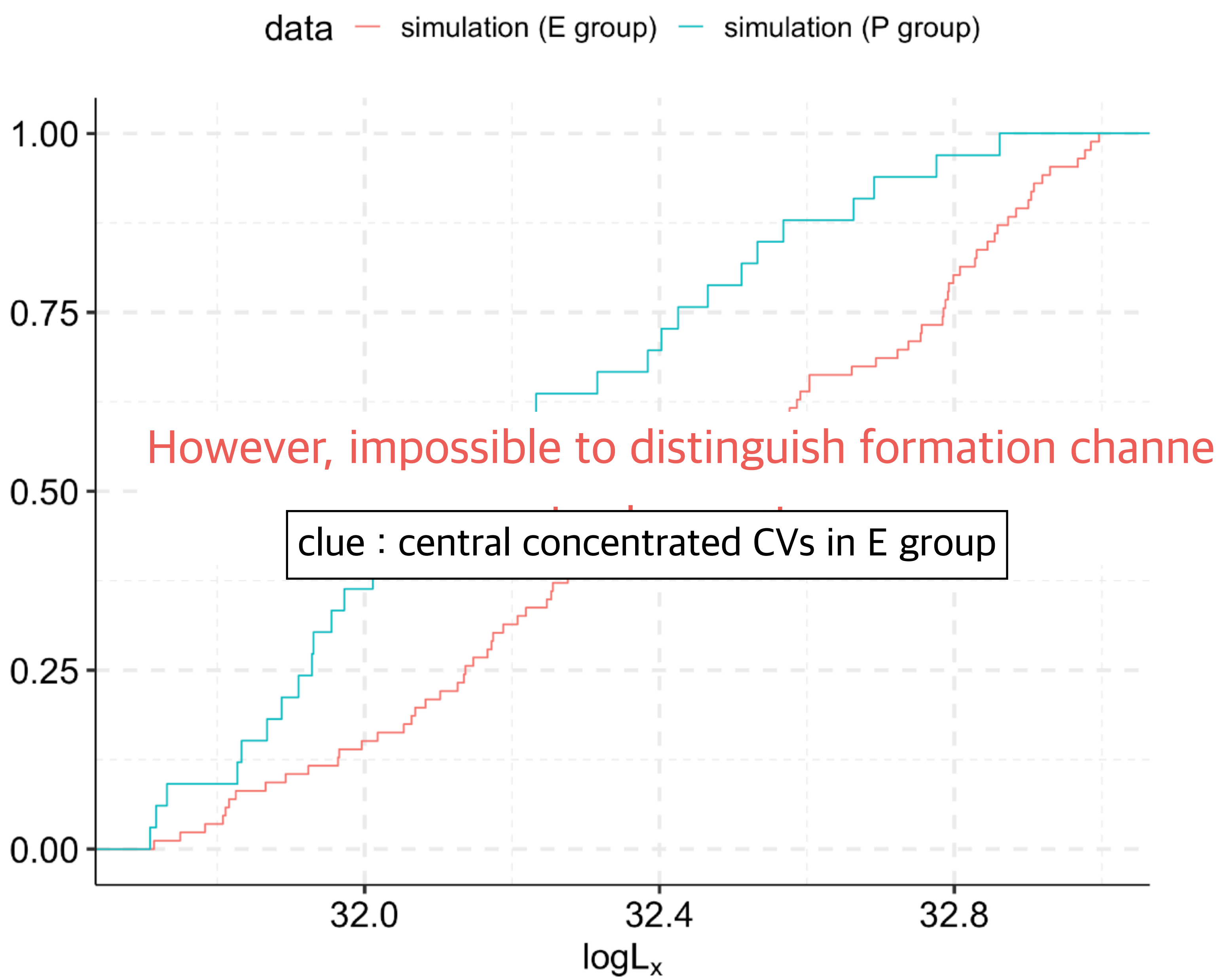
X-ray luminosity

- Simply adopt slowly rotating WD (Patterson & Raymond, 1985) :

$$L_{\rm X} = \varepsilon\, \frac{G\, M_{\rm WD}\, \dot{M}_{\rm dQ}}{2\, R_{\rm WD}}$$

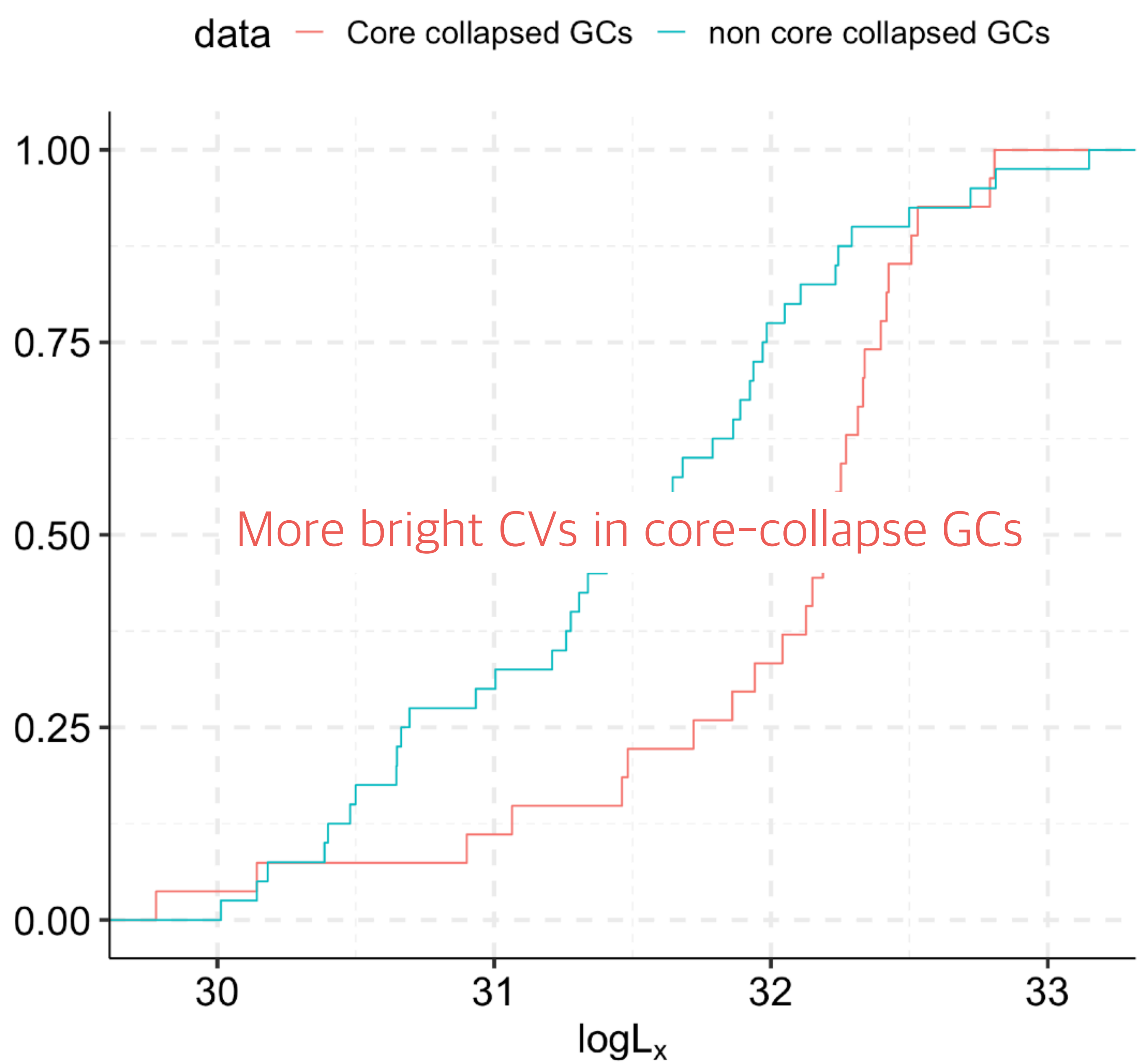
- ε = 0.5, for the fraction of the X-rays emitted inwards and absorbed by the WD
- L_X cumulative distribution function (CDF) for X-ray distribution for P & E groups

L_X cumulative distribution function (CDF)



E group and P group distribution in whole 81 GC models at 12 Gyr (PDP)

L_X cumulative distribution function (CDF)



In the observation, similar phenomena in core-collapsed GCs due to mass segregation effect of the cluster

Observationally detected CV

Observational CV fraction

- CVs in core-collapse GCs dominate comparably higher fraction
- More sample will be adopted in the future

CV domination of L_x in different GCs	
GC name	CV fraction in L_x^{tot}
47 TUC	37.27%
Omega-cen	7.21%
NGC6397	84.32%
NGC6752	88.14%

Core-collapse (NGC6397, NGC6752)

: Information for core status from Harris catalog (2010)

- Do bright CVs in core-collapse GCs form via dynamical interaction?

Core-collapse vs non-core-collapse GC

Observational CV fraction

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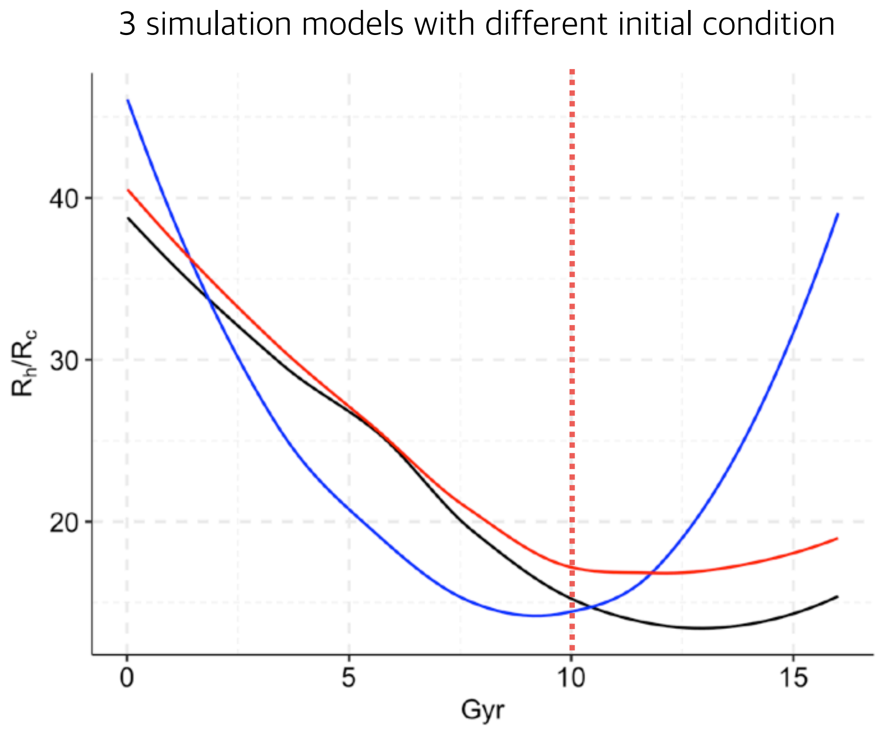
Core-collapse

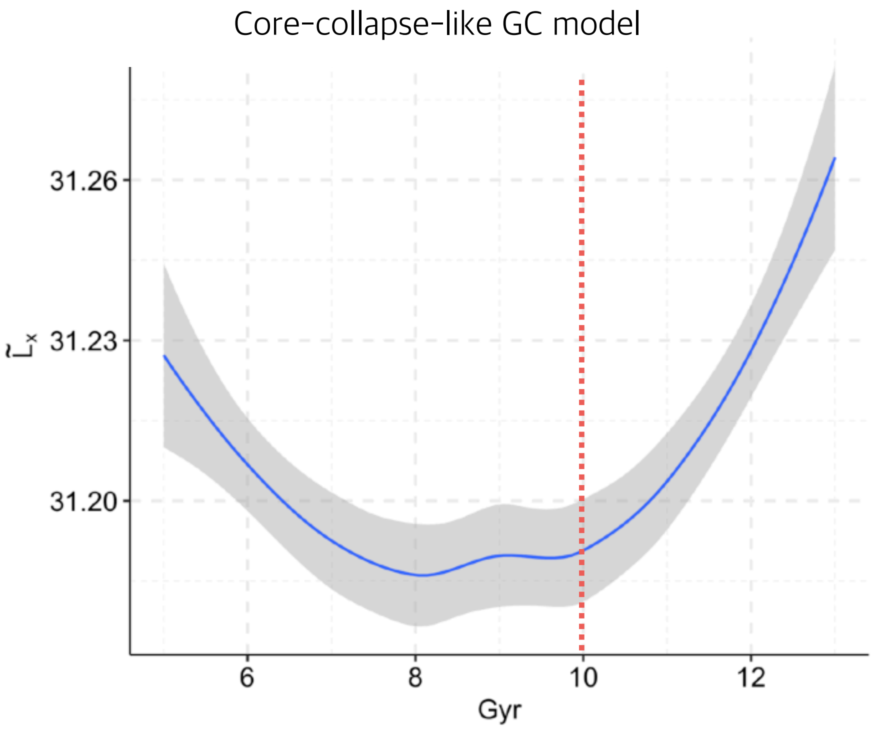
How we define core-collapse status in MOCCA GC models?

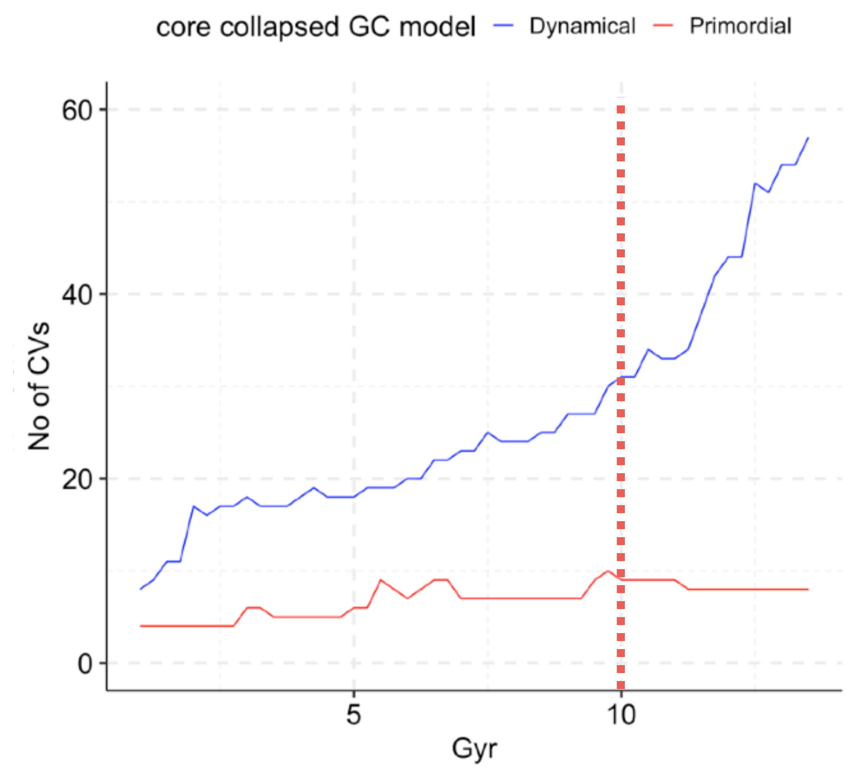
- Tracking the ratio of core-radius & half-mass radius ratio of cluster
- Checking the X-ray luminosity variation
- Number of CVs along the time

Core-collapse vs non-core-collapse GC

CV domination of L_x in different GCs

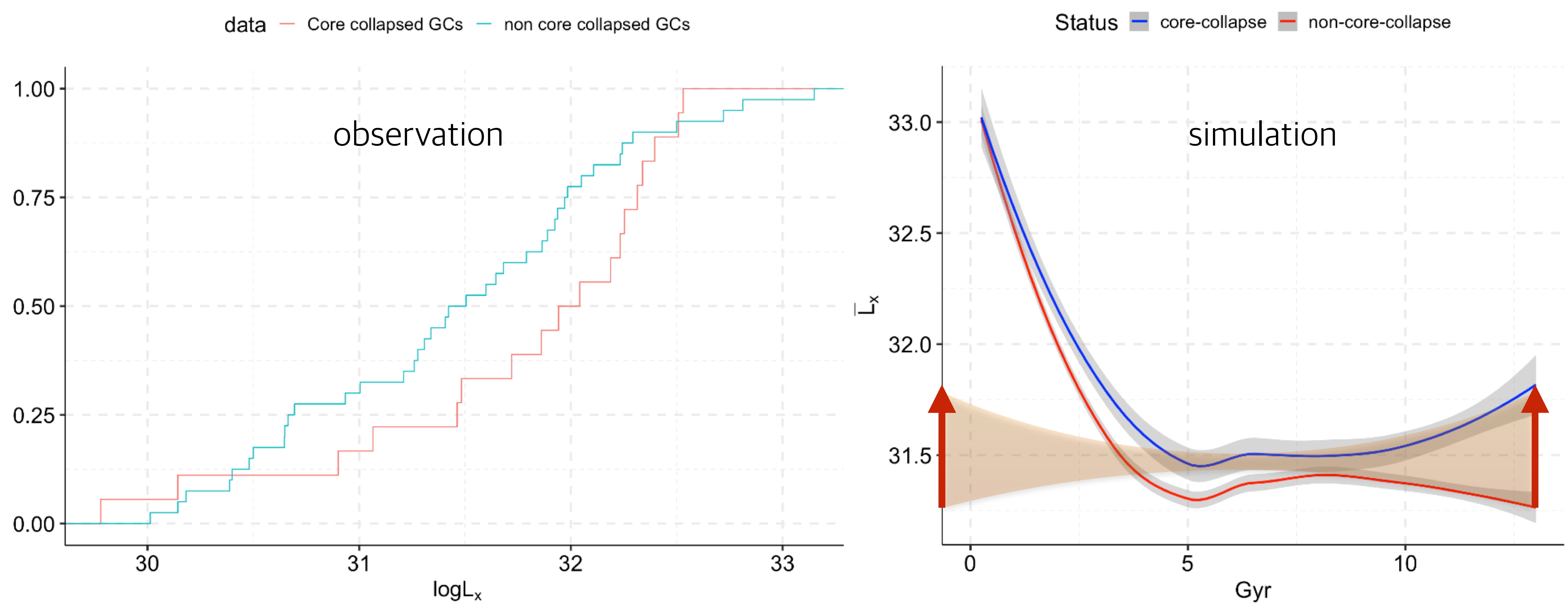






In this MOCCA model, core-collapse begins at ~10 Gyr!

Core-collapse vs non-core-collapse GC



Once we use mean values in both observation and simulation,

$log\Delta L_{X,obs} \sim 0.51$ & $log\Delta L_{X,sim} \sim 0.55$

Further statistical test

Anderson-Darling test for dominant factors

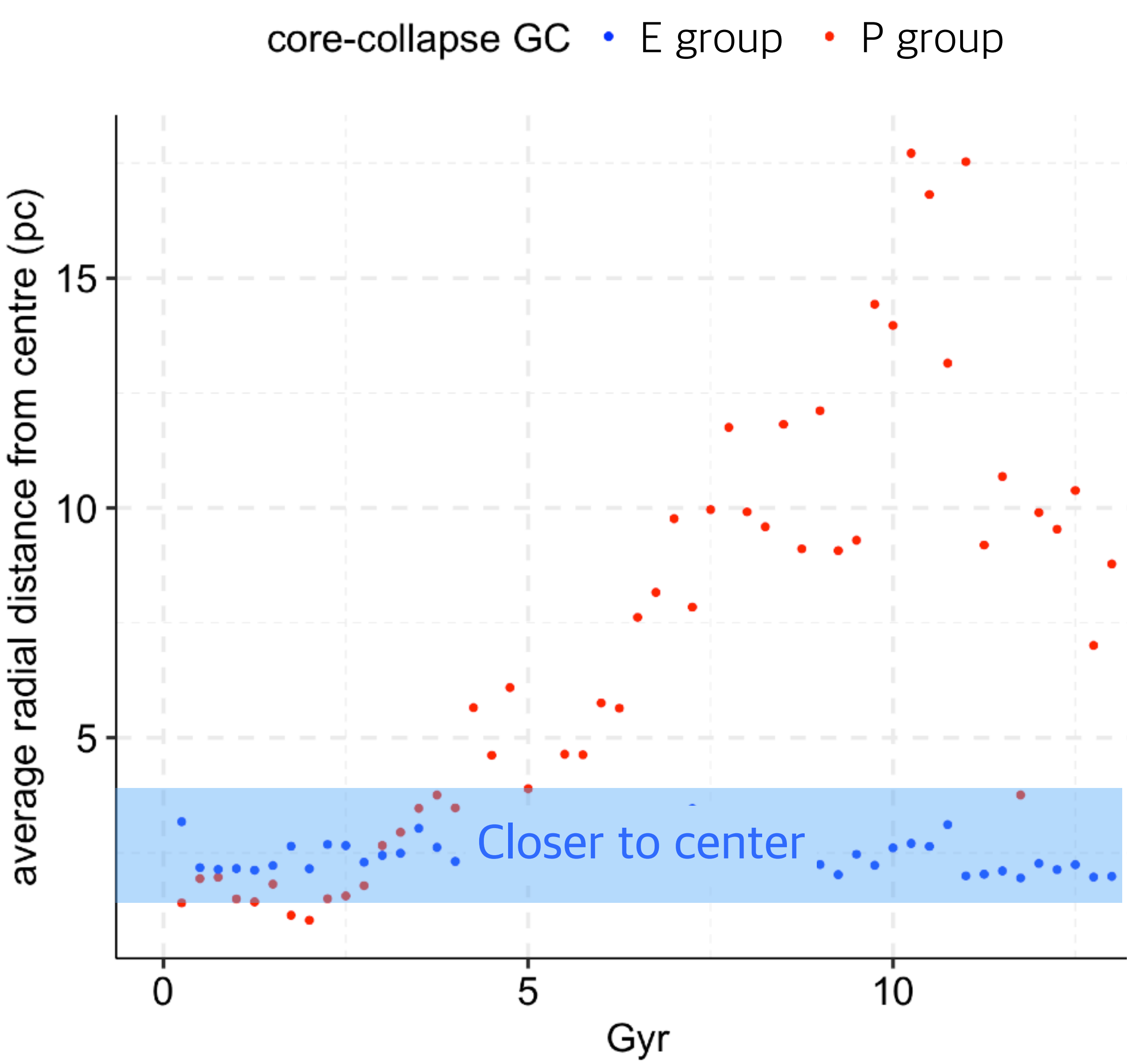
- Which factors are mostly dominate for bright CVs?
- The bigger difference from mass of WD and radius of WD

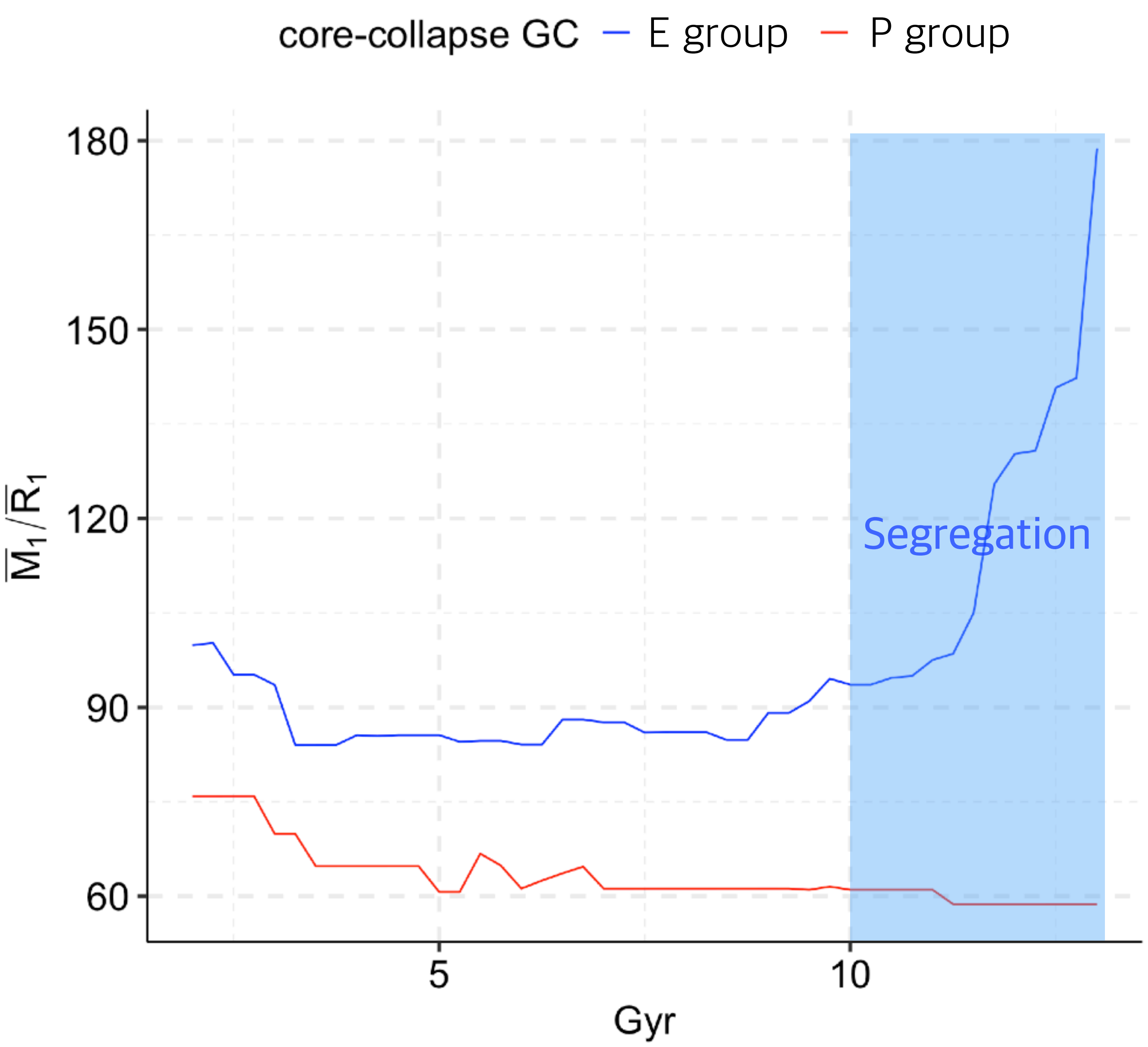
Anderson-Darling test		
Parameter	AD value	P-value
Semi-major Axis	10.2	7.865e-06
$\log L_x$	13.9	7.453e-08
$\log M_{dot}$	29.7	1.483e-16
Orbital period	29.3	2.423e-16
M_{ms}	43.1	6.702e-24
M_{wd}	94.1	5.741e-52
R_{wd}	94.1	5.741e-52

P vs E in total 81 models

Dominant factors

Comparison of Dynamical formed CVs & Primordial CVs





- CVs in E group are more concentrated to the core
- According to the method for core-collapse GC, E group CVs increase after core-collapse stage
- It can be the result of 1) mass segregation & 2) increase of core density

Summary & Future work

Summary & Future scheme

Summary

- Dynamical formed CVs can have dominant fraction of core-collapse GC
- M-R relation can explain deeper gravitational potential & mass segregation effect of GC
- CV population can be a new parameter for considering the evolutional status of GC
- Not only CVs, the other compact objects would tell us more about GC dynamics

Future scheme

- LMXB and BH-BH binaries in GC can be new target with MOCCA
- Exotic BH binary such as large eccentricity or tilted rotational axis BH binaries due to dynamical interaction
- Updating MOCCA code for more energetic binary