ROTATING GLOBULAR CLUSTERS IN THE GAIA ERA

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FOR A LONG TIME...

Globular clusters have been described as stellar systems having:

- **simple** geometry
- **simple** dynamics
- **simple** stellar population

… BUT NOW WE KNOW BETTER!

Globular clusters are **complex** stellar systems:

- rotation
- pressure anisotropy
- external tidal field
- multiple populations
- black holes (stellar mass, IMBH) and other exotica
- …

This complexity needs to be taken into account and to be treated properly!

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WHY IS ROTATION IMPORTANT?

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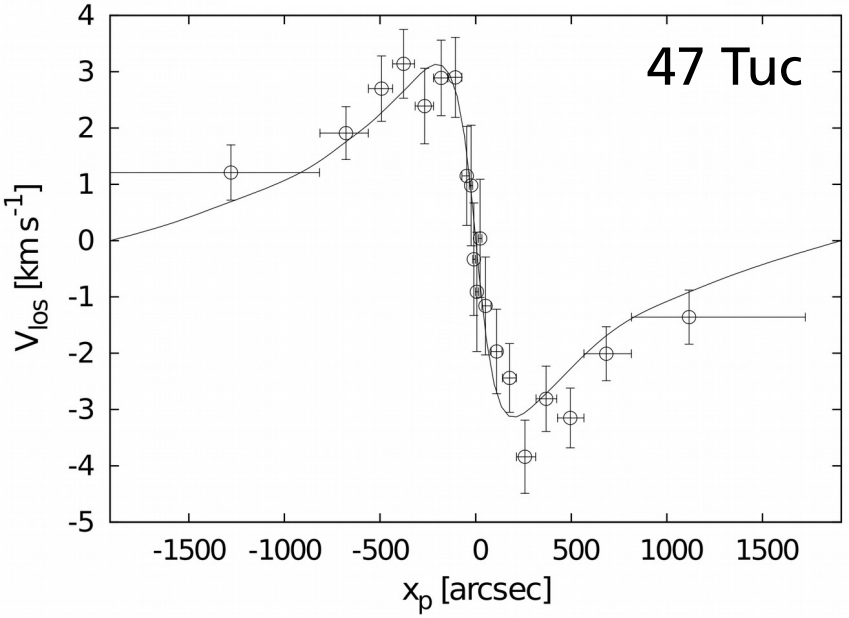

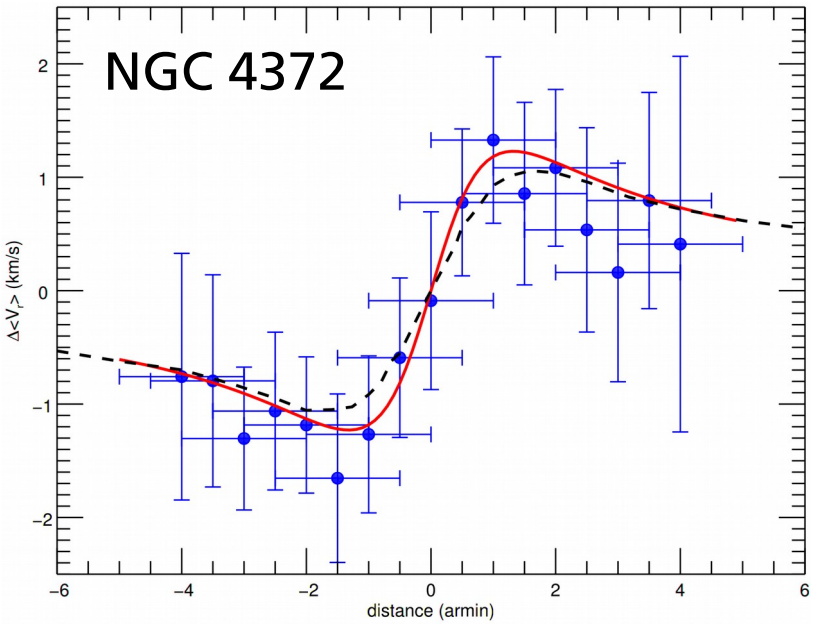

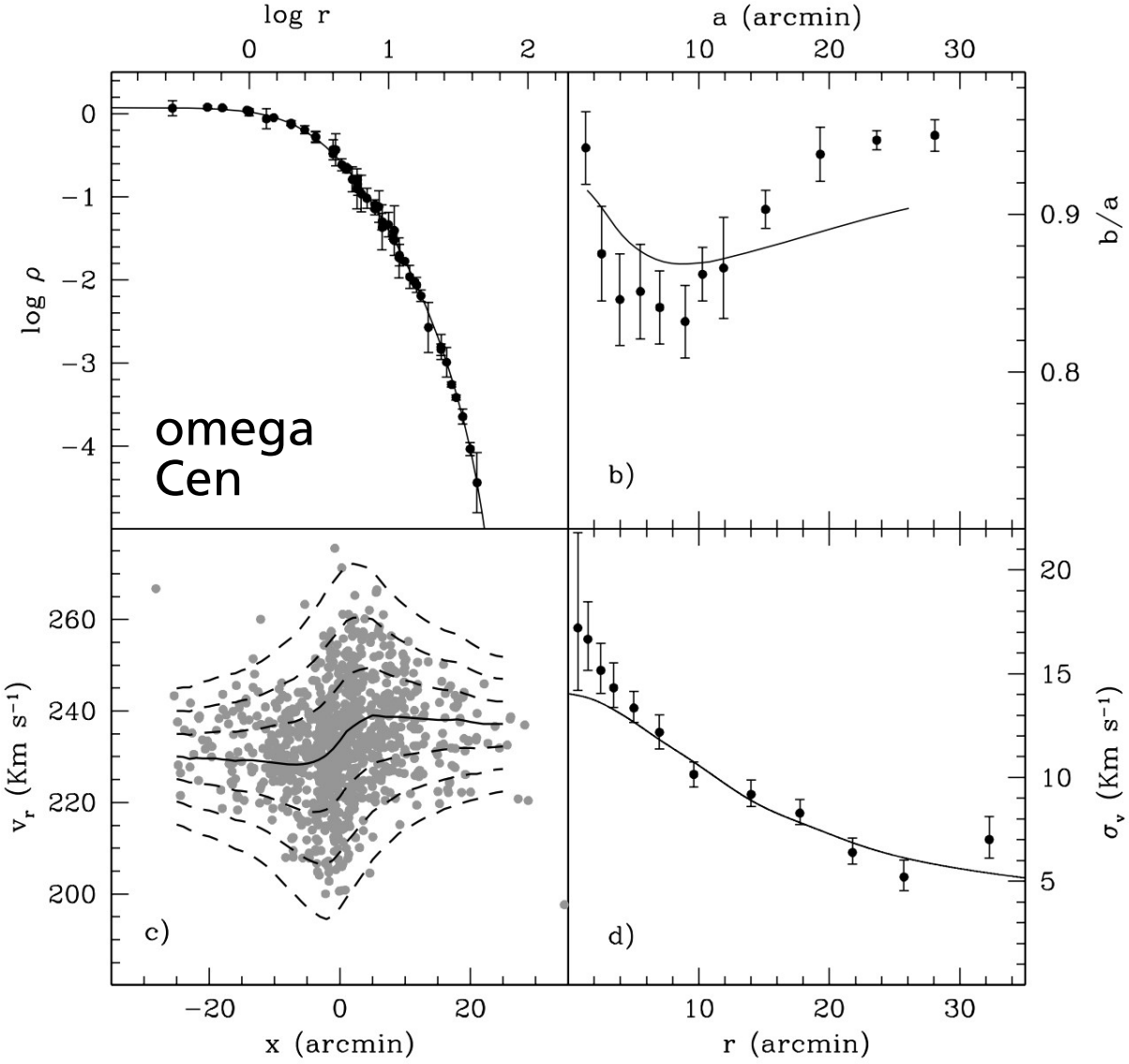

Sollima et al. 2009
Bianchini, Varri, Bertin, & Zocchi 2012
Kacharov, Bianchini, et al. 2014

WHY IS ROTATION IMPORTANT?

Also detected with proper motions!

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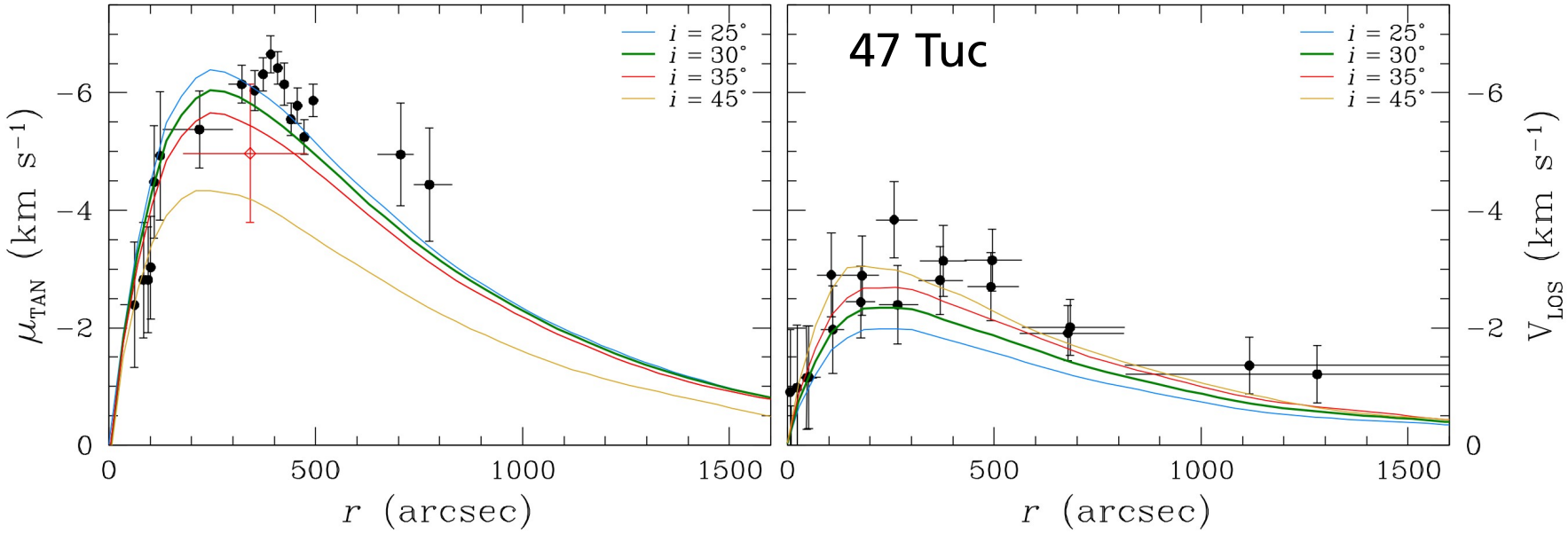

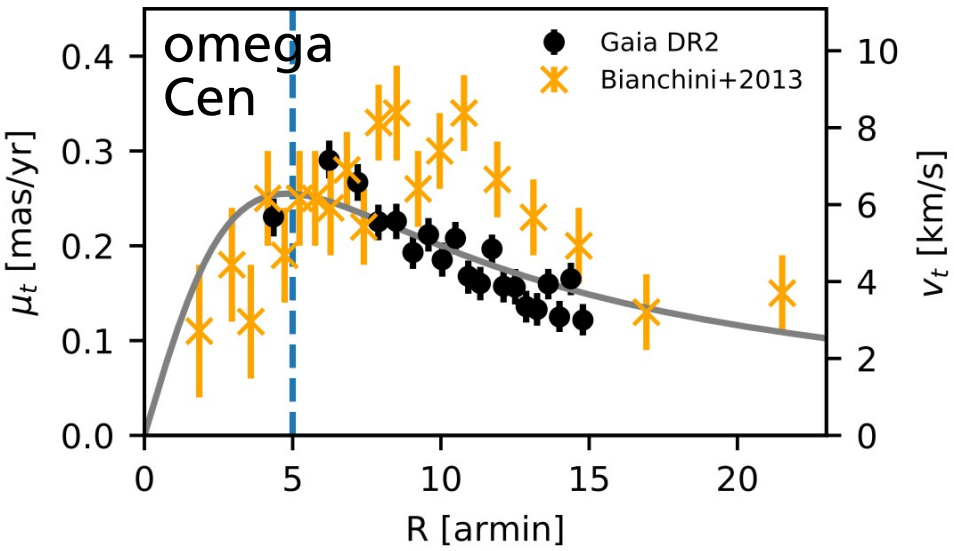

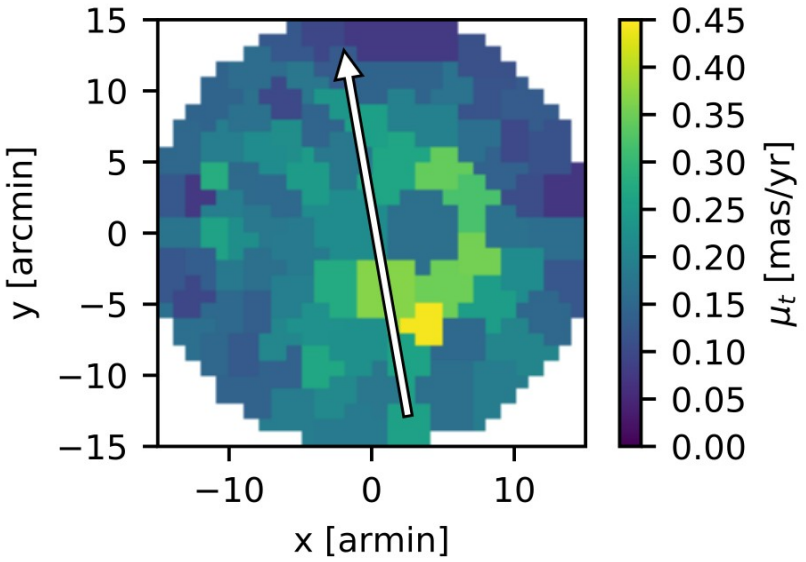

Bellini, Bianchini, Varri, et al. 2017
Bianchini et al. 2018

WHY IS ROTATION IMPORTANT?

Different rotation in different populations?

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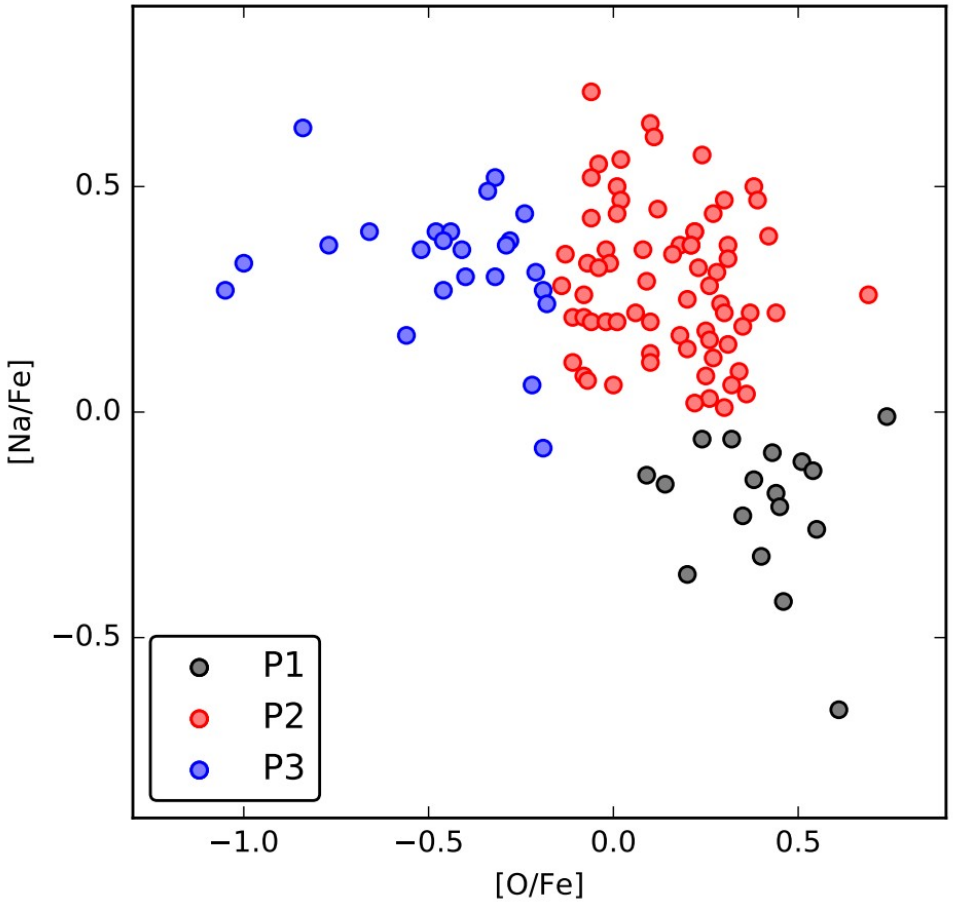
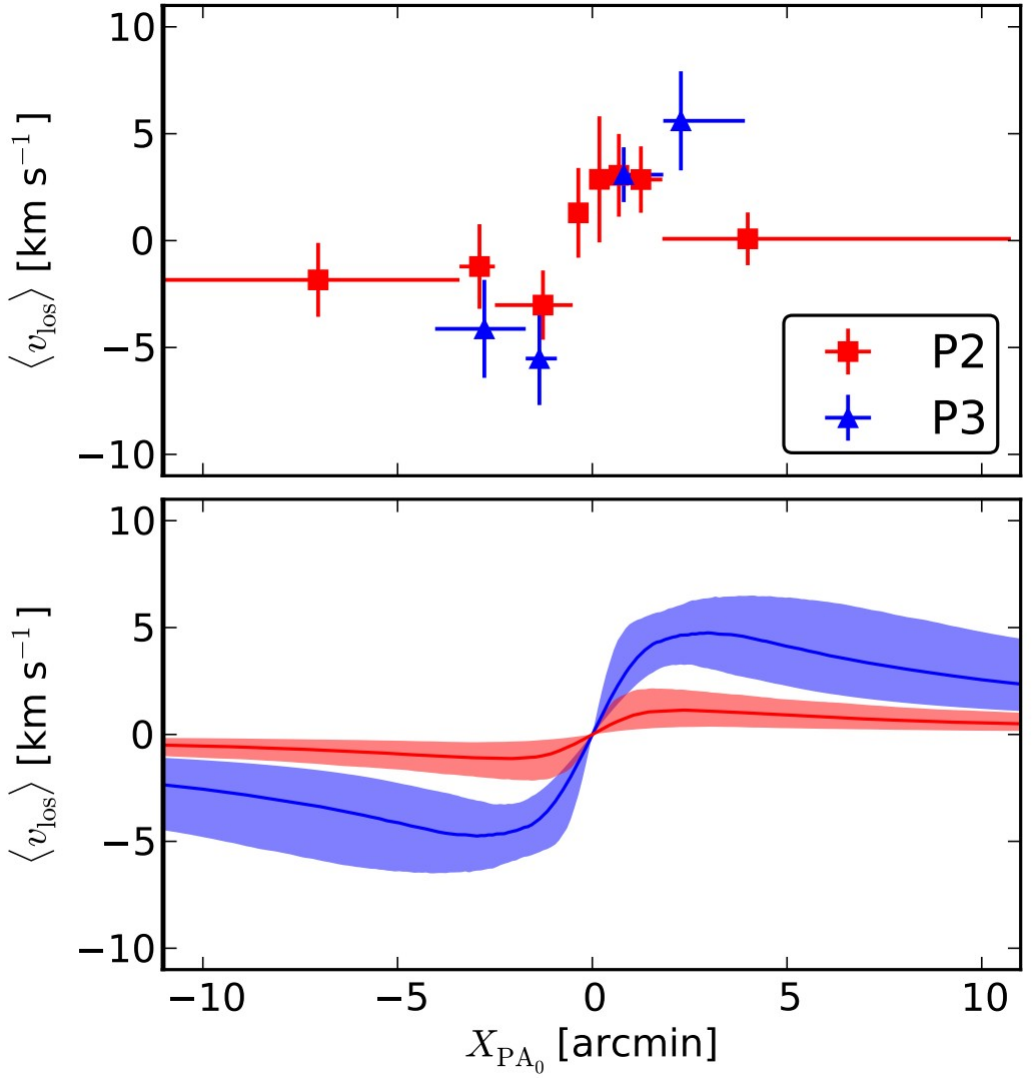
Different rotation in different populations?

Cordero et al. 2017
NGC 6205 [M13]





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Possible responsible for globular clusters morphology

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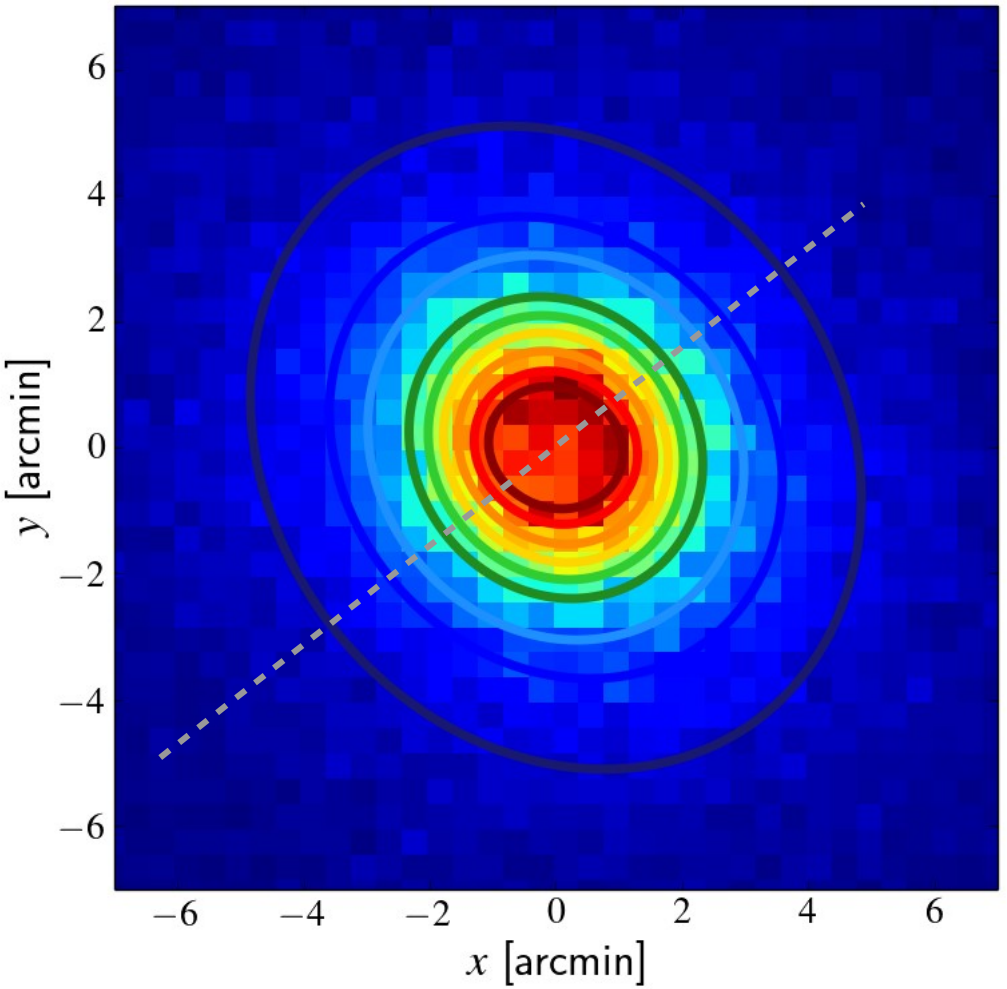
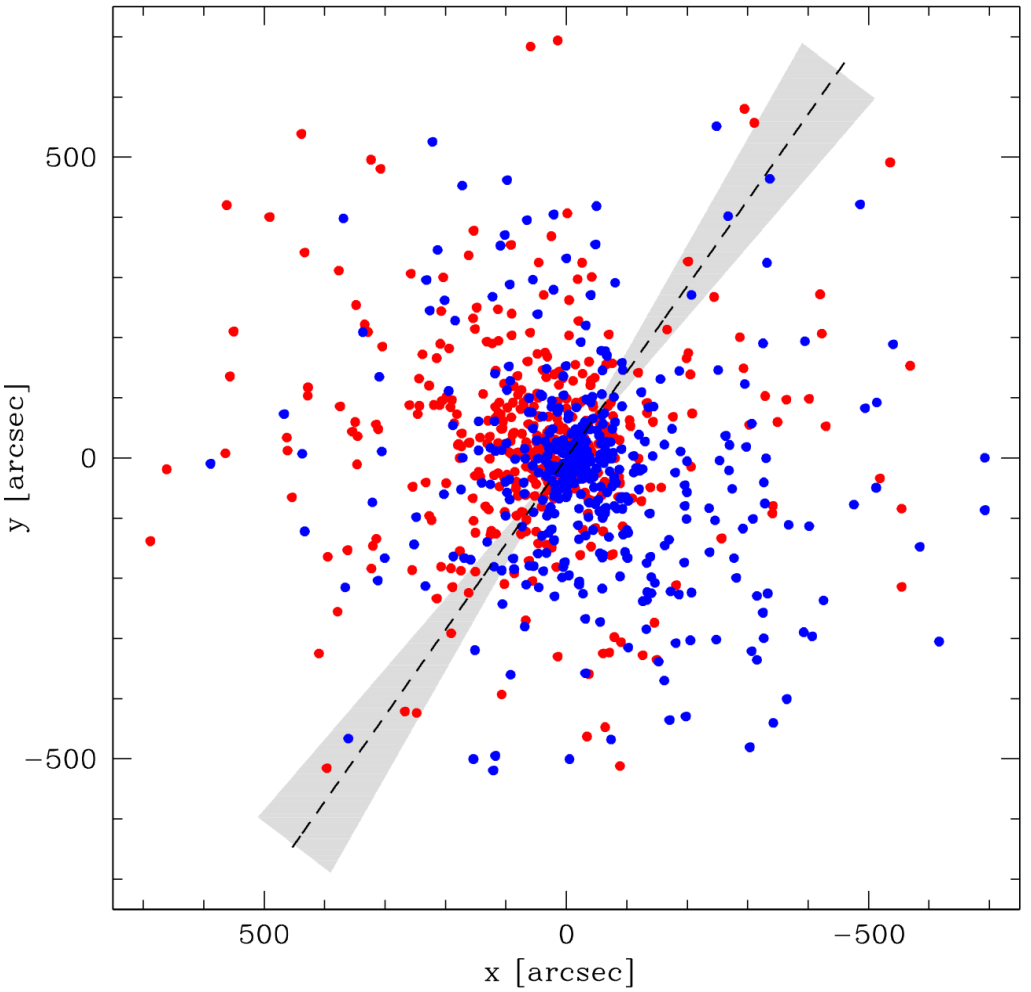
NGC 5904 [M5]





Stetson et al., to be submitted

Lanzoni et al. (2018)

ROTATING MODELS

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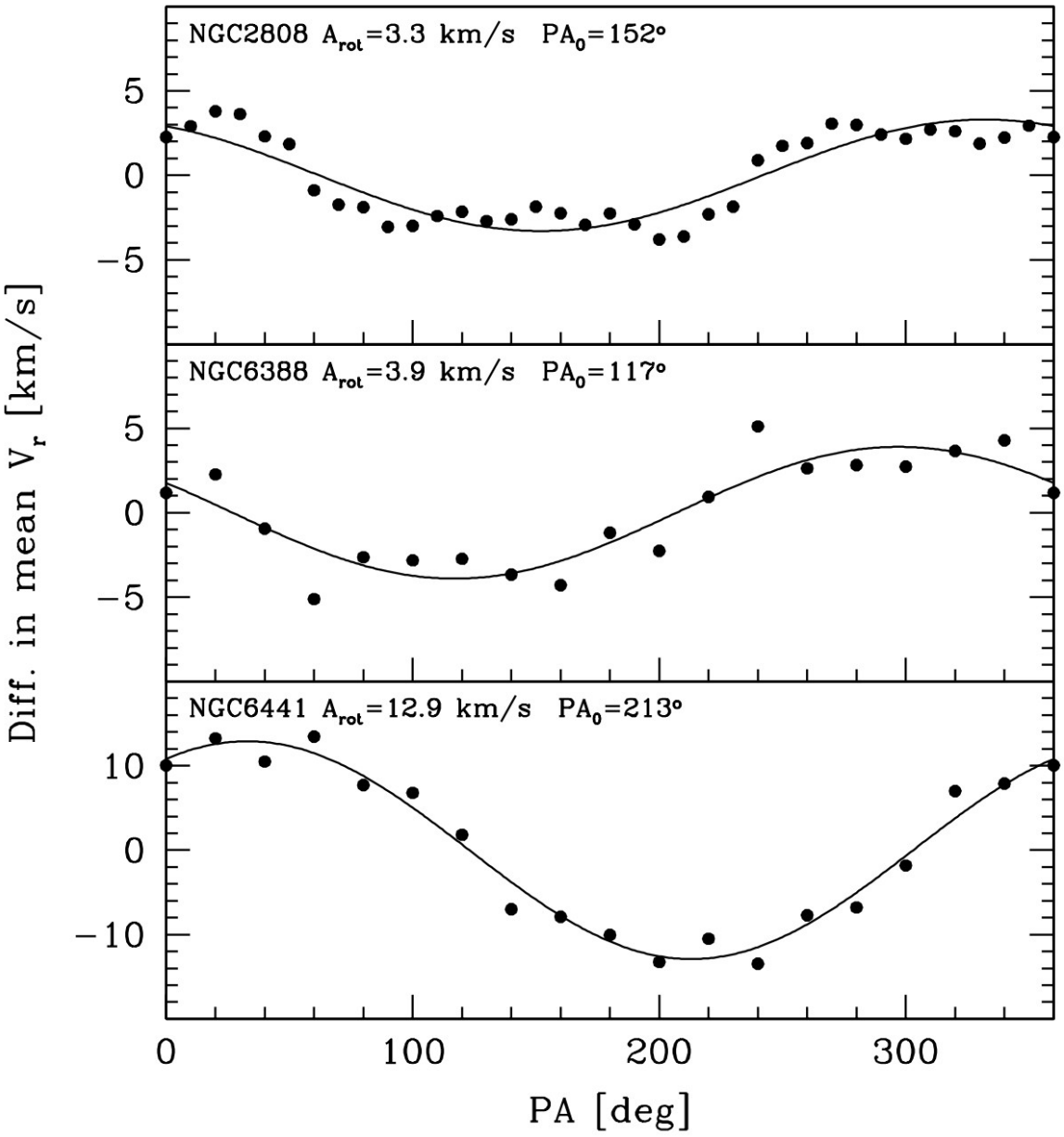
Goals:

- to characterize rotation
- to understand its properties with respect to external tidal field and in different evolutionary stages



Bellazzini et al. 2012

ROTATING MODELS

Dynamical models defined from distribution function

- Prendergast & Tomer 1970; Wilson 1975; Jarvis & Freedman 1984; Lagoute & Longaretti 1996; Lupton & Gunn 1987; Einsel & Spurzem 1999; Varri & Bertin 2012

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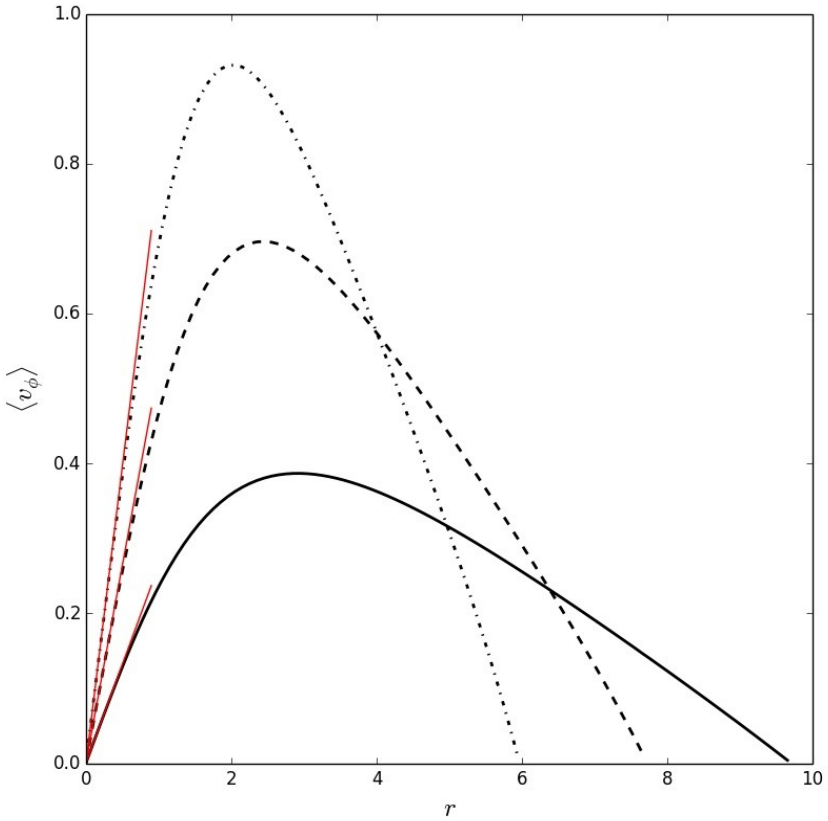
- Zocchi & Varri, in prep.

$$f(E, J_z) = A\, E_\gamma \left(g, -\frac{E - \phi(r_t)}{s^2} \right) \exp\left(\frac{\omega J_z}{s^2} \right)$$

$$E_\gamma(g, x) = \frac{\exp(x)\gamma(g, x)}{\Gamma(g)} \qquad g > 0$$

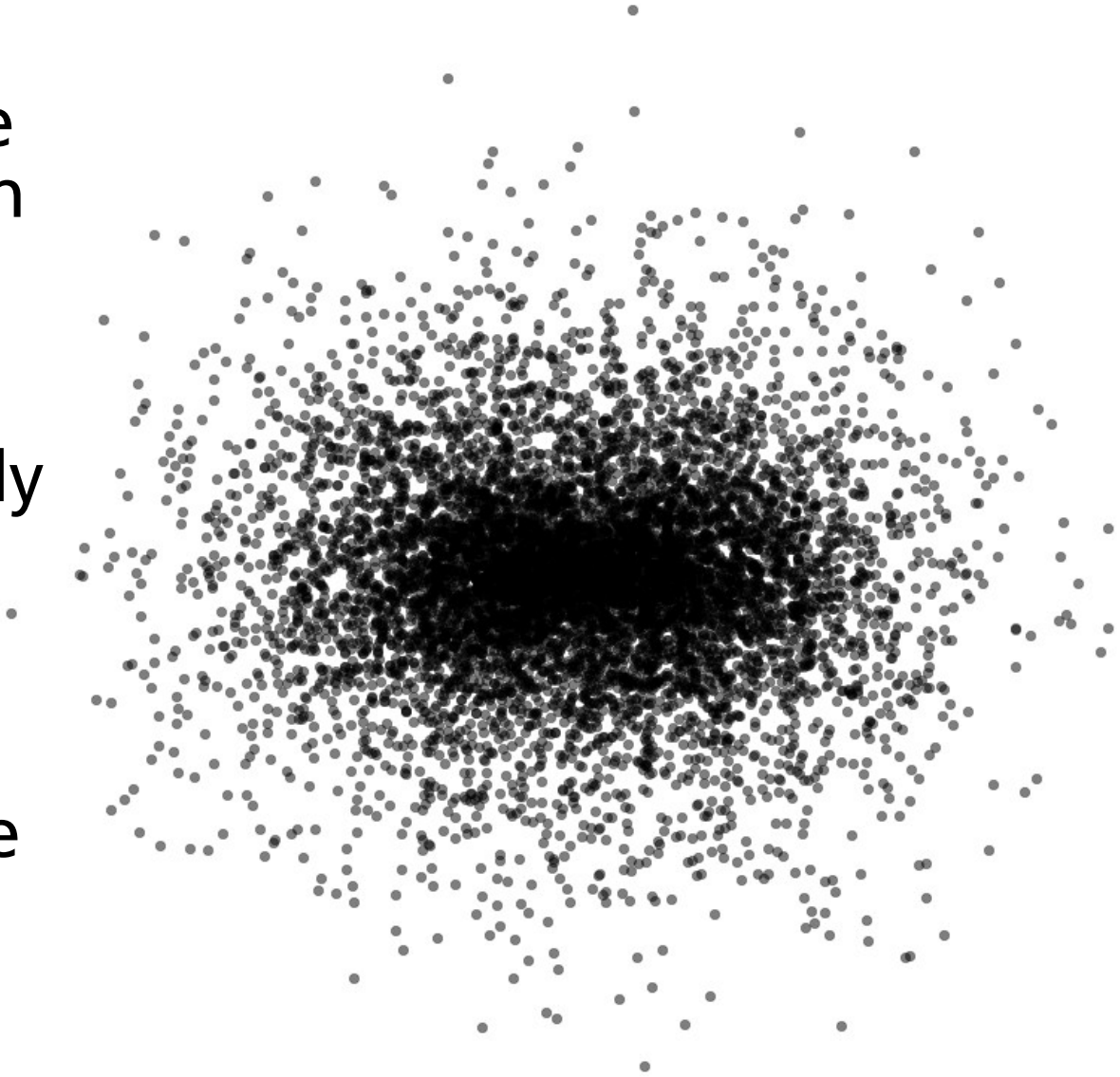
$$E_\gamma(g, x) = \exp(x) \qquad g = 0$$

$$\hat{\omega} = \frac{\omega}{\sqrt{4\pi G \rho_0}}$$



MAIN PROPERTIES

- The models are axisymmetric, and the **flattening** depends on the rotation strength
- The **rotation** is differential (solid body behaviour at the centre)
- The models are **isotropic** at the centre and at the edge, and radially **anisotropic** in the intermediate region



ISODENSITY CONTOURS

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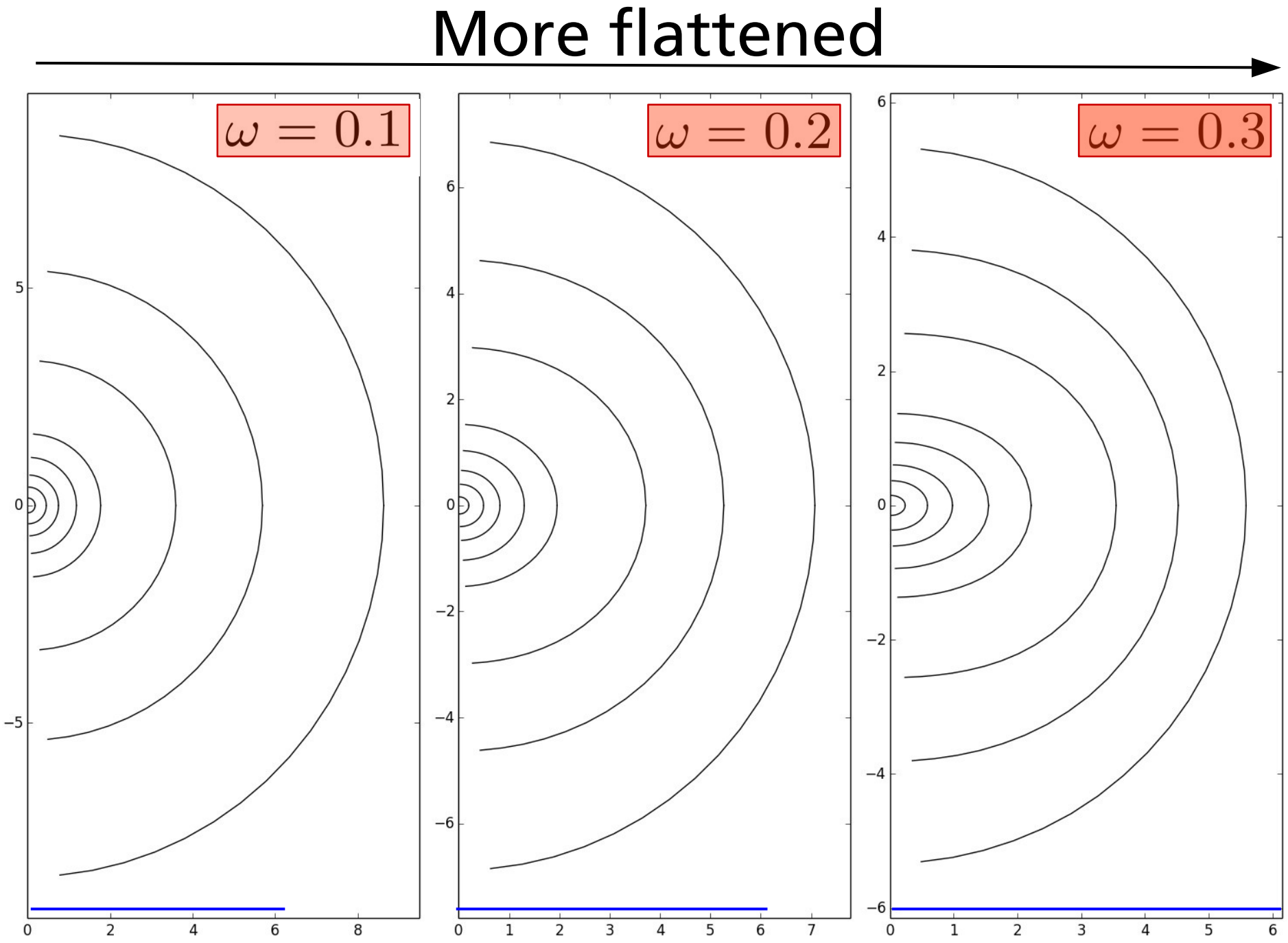
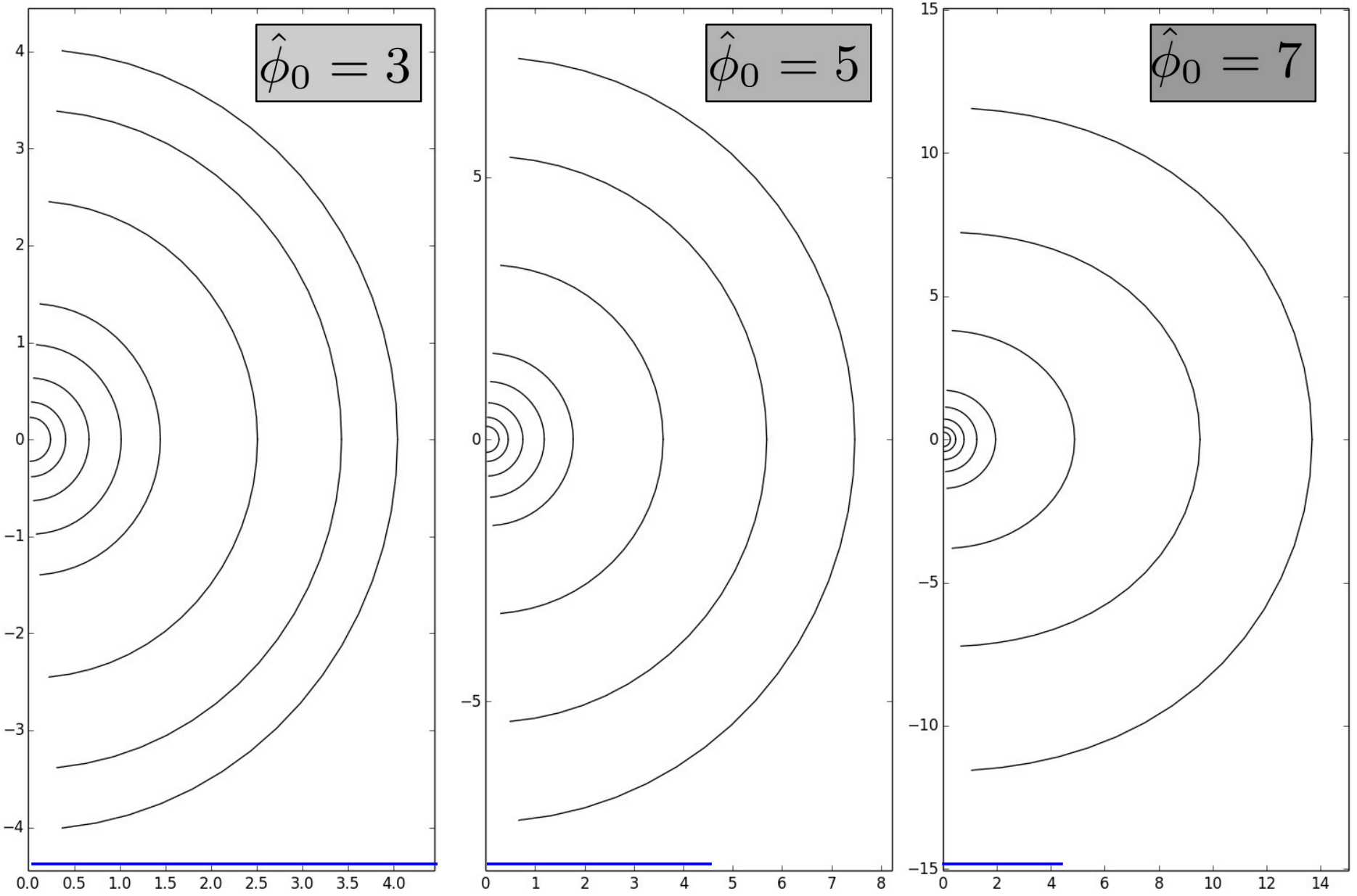


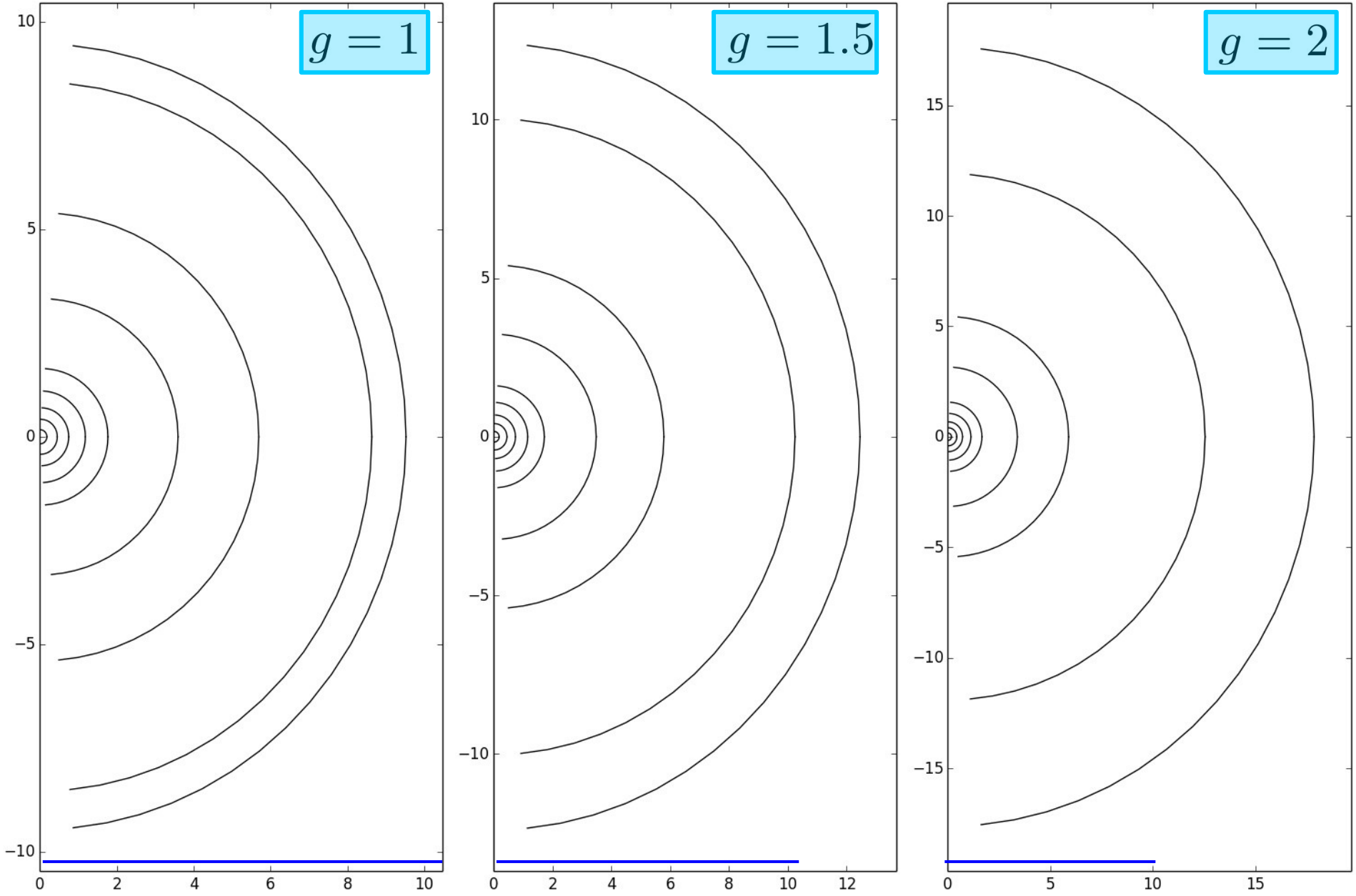
ISODENSITY CONTOURS

More concentrated



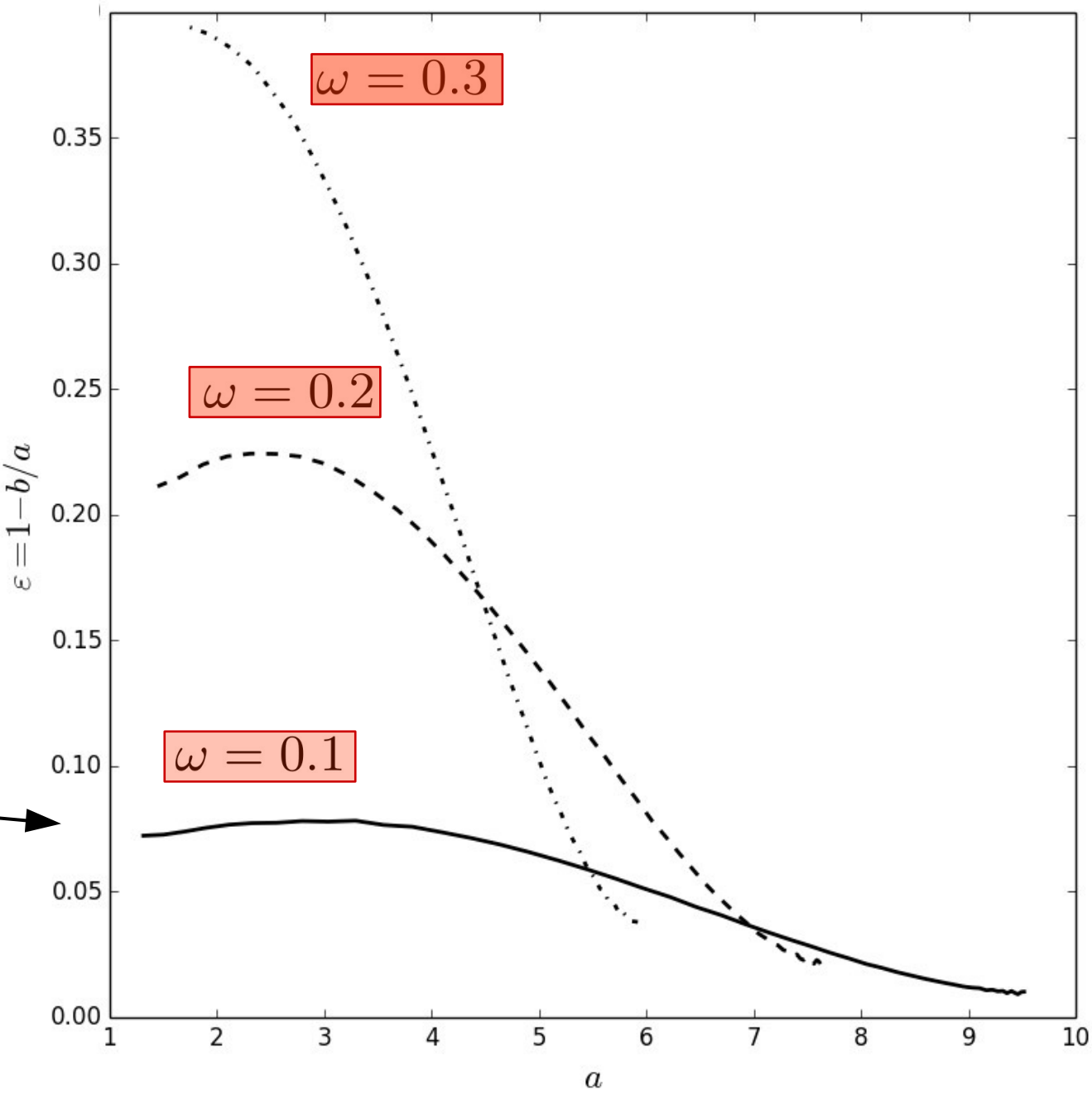
ISODENSITY CONTOURS

Shallower truncation



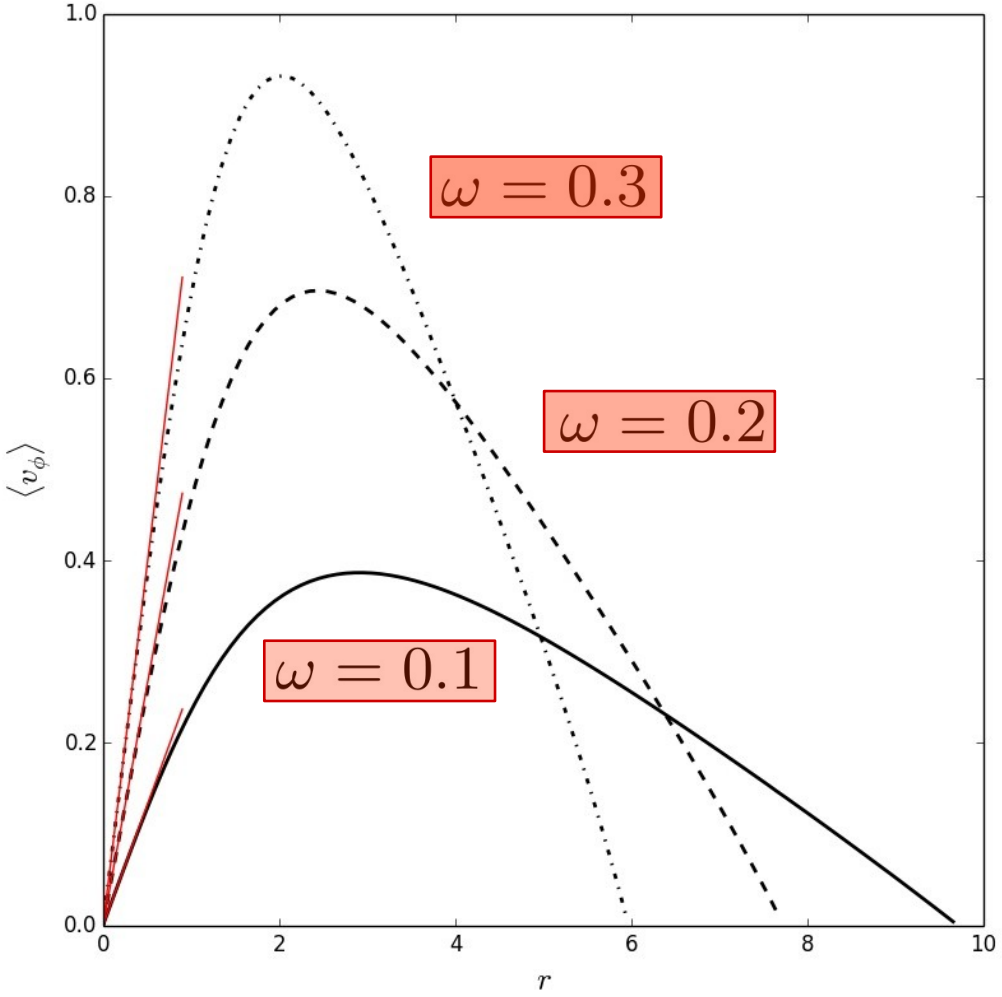
ELLIPTICITY PROFILE

Globular Clusters!

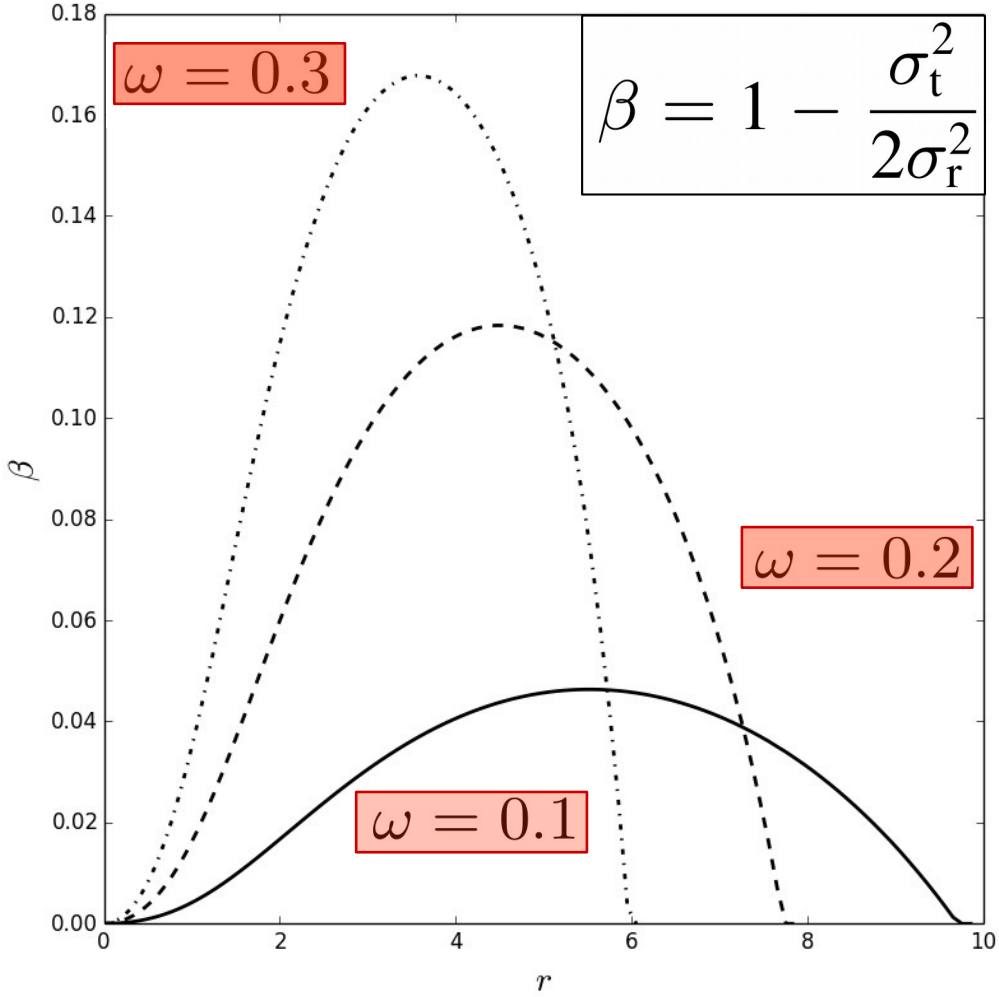


KINEMATIC PROFILES

Rotation curve



Anisotropy



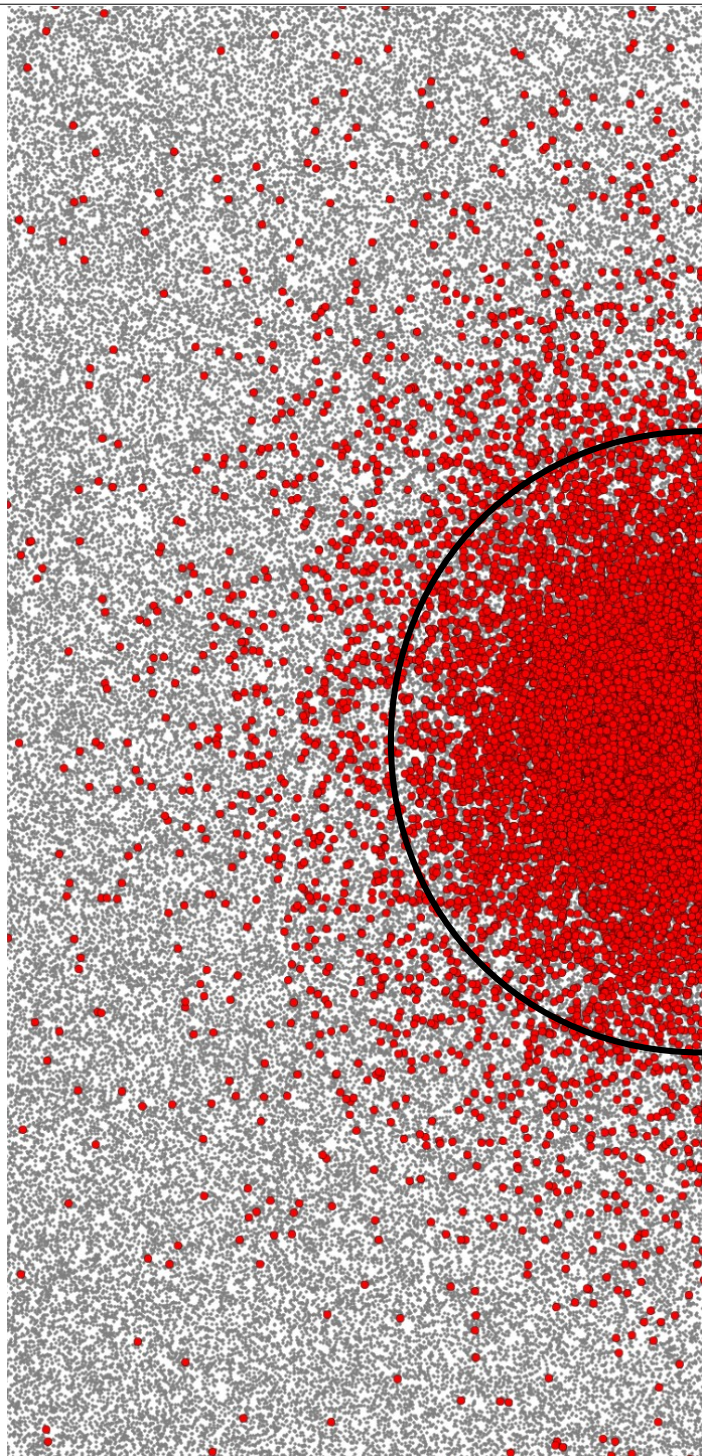
Peaks are NOT in the same location!

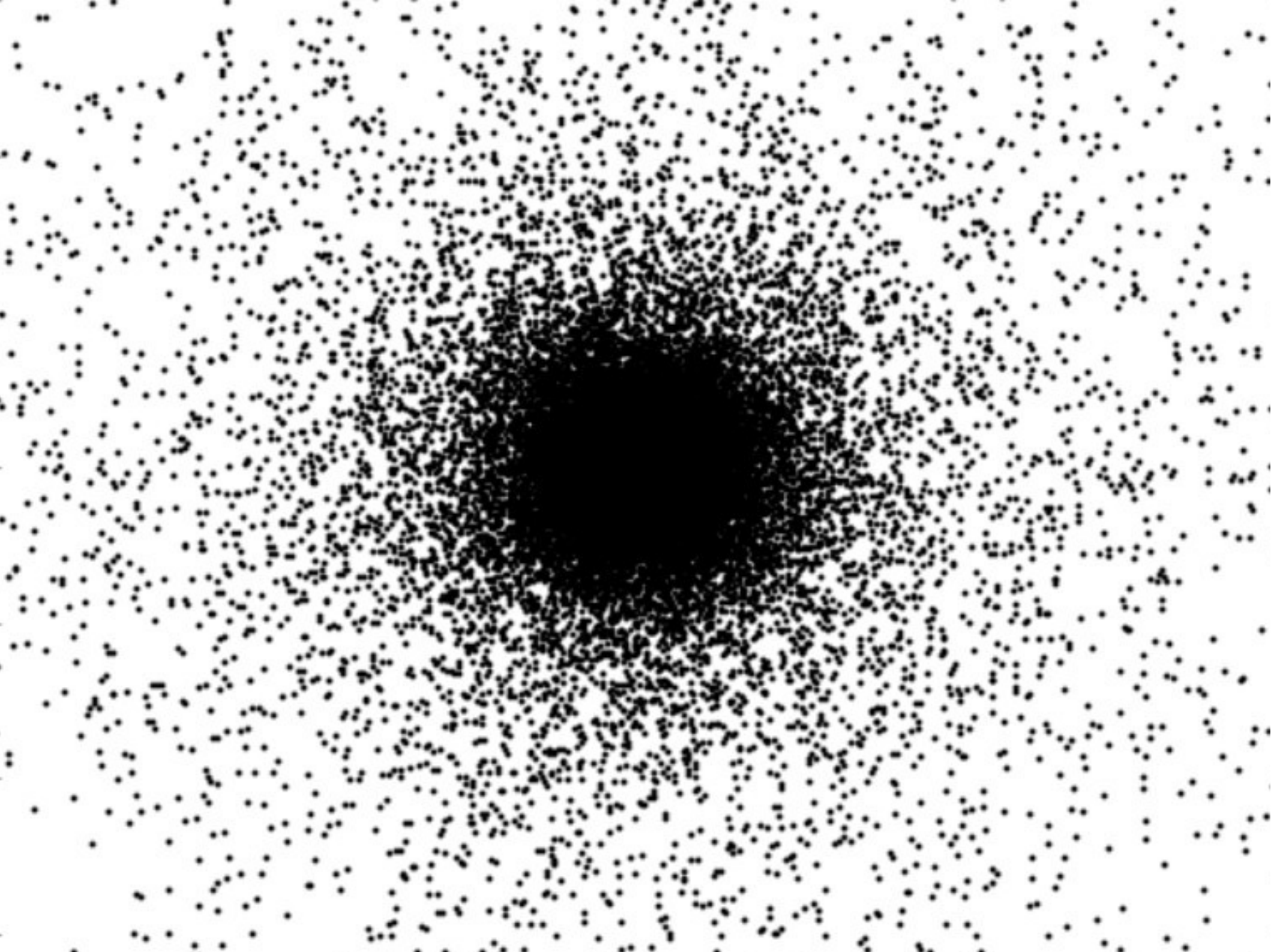
SUMMARY

- Globular clusters are **complex** stellar systems, and this complexity needs to be taken into account and to be treated properly!

- **Rotation** is an interesting dynamical ingredient to explore and characterize, as its property carry information about the past evolution of clusters.

- **NEXT STEP -** Compare models with the data of Galactic globular clusters and determine the property of rotation, anisotropy and tidal effects!





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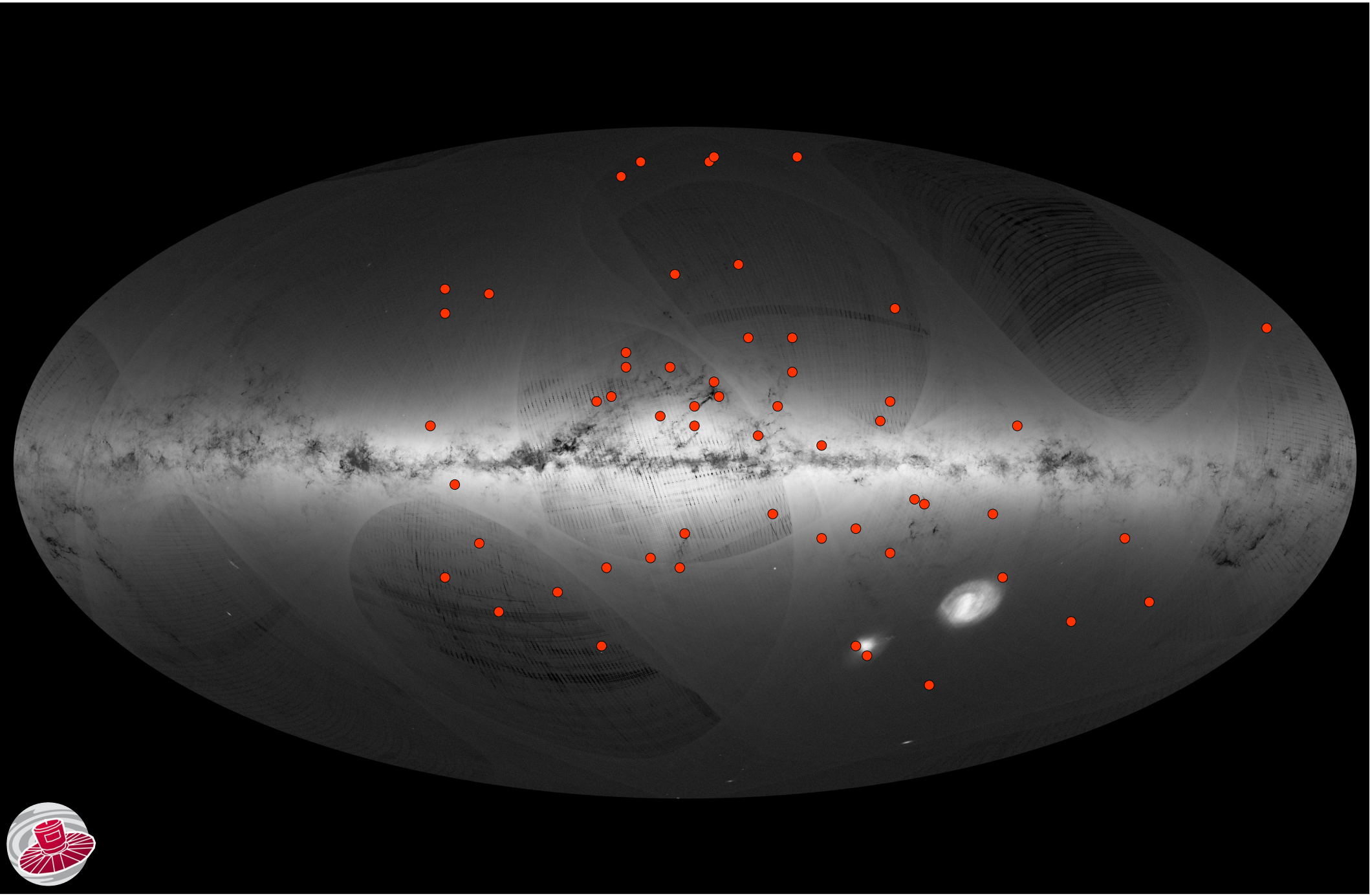
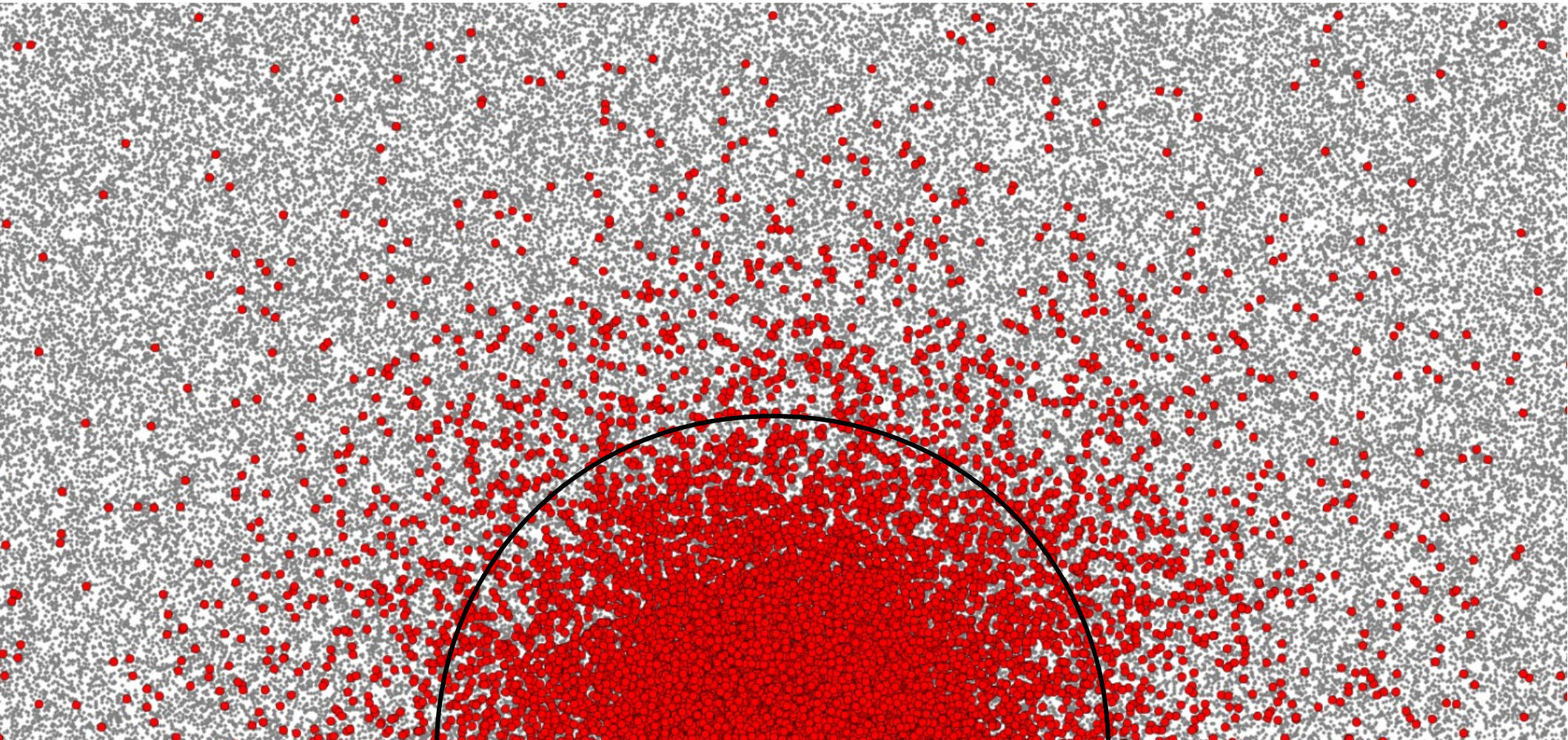


WHY IS GAIA SO IMPORTANT?

Coverage of the entire extent of stellar clusters

Improved membership determination

Phase space (almost) fully available!