KINEMATICAL SIGNATURES OF IMBHs IN GLOBULAR CLUSTERS

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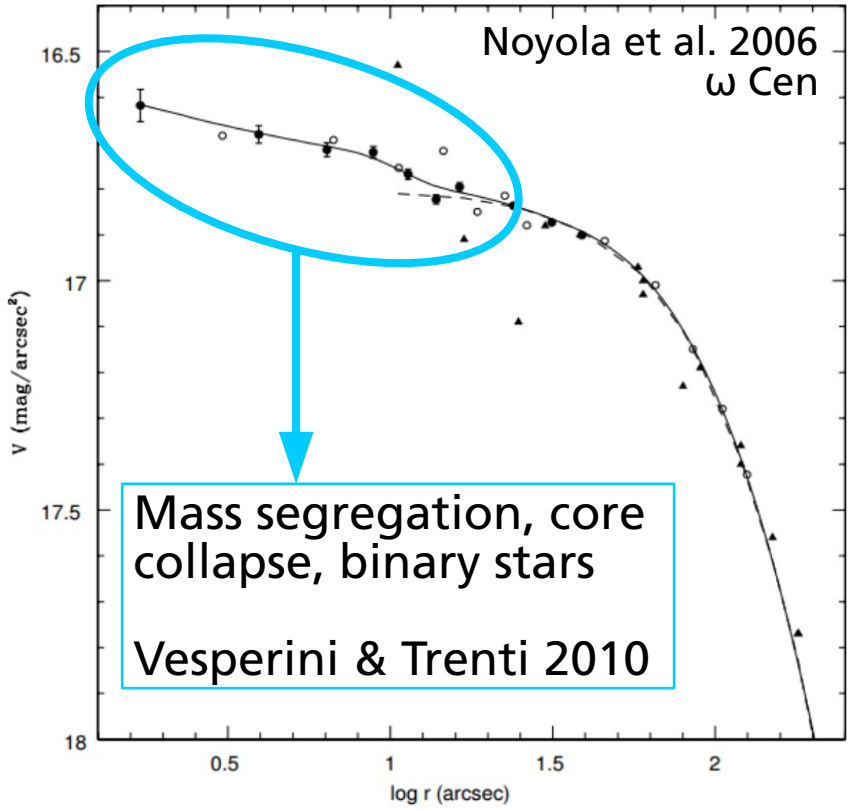
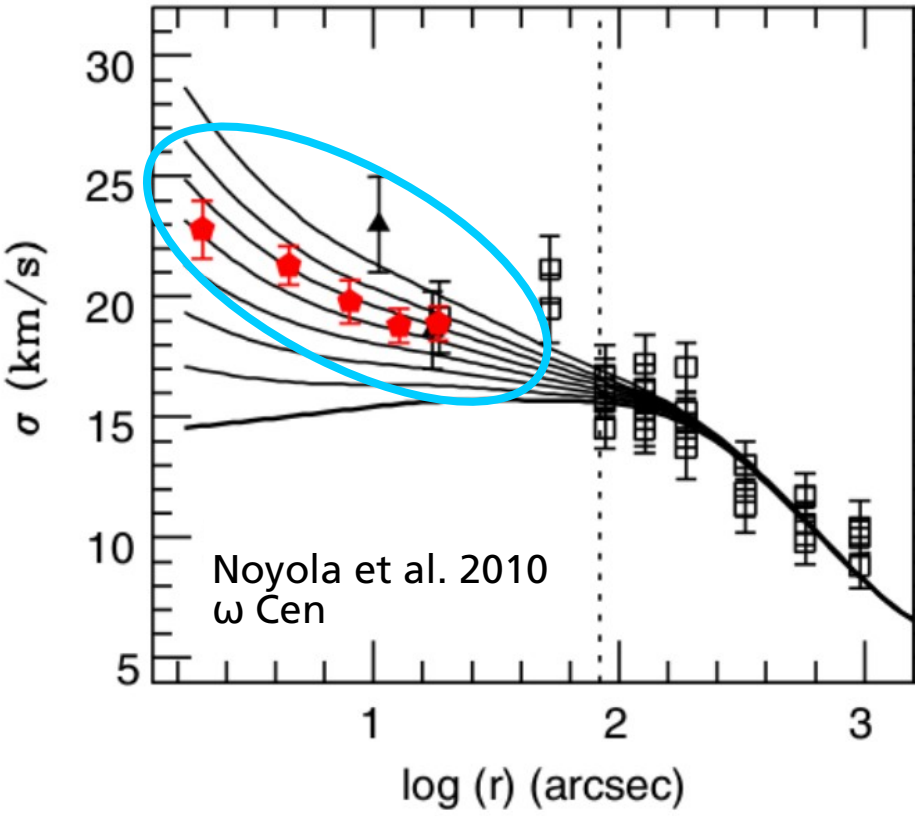
HOW DO WE DETECT IMBHs?

PHOTOMETRY:
shallow cusps in the
surface brightness profile



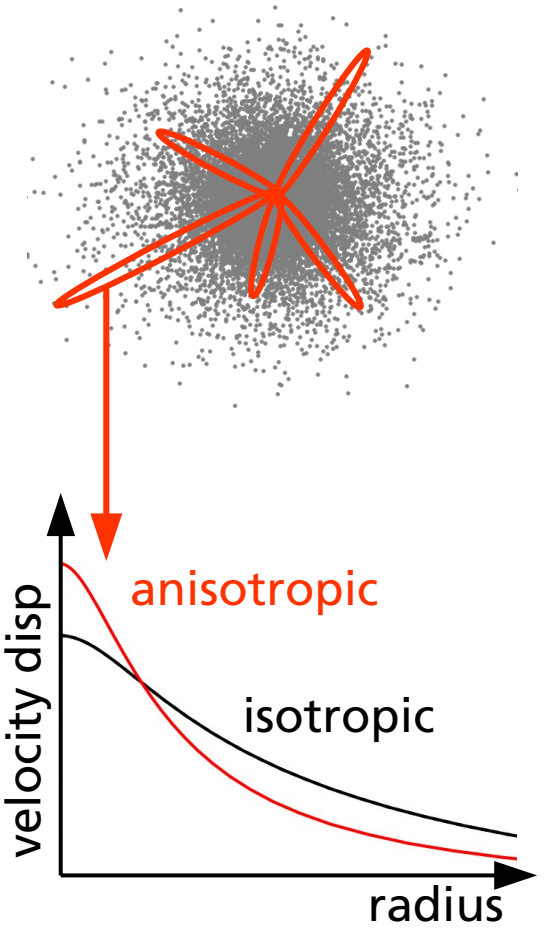
KINEMATICS:
central rise in the
velocity dispersion profile



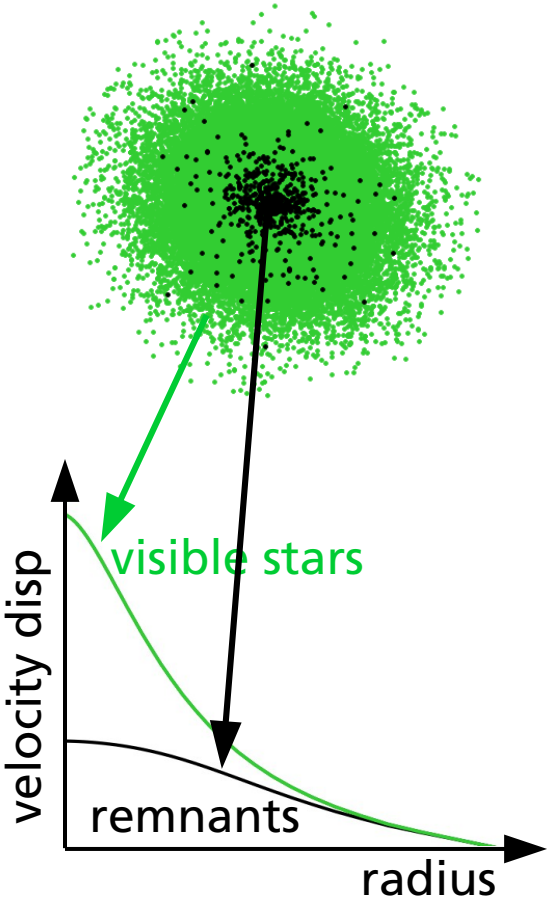
These signatures are **NOT UNIQUE**,
and can also be accounted for by different processes!

DEGENERACY OF THE KINEMATIC SIGNATURE

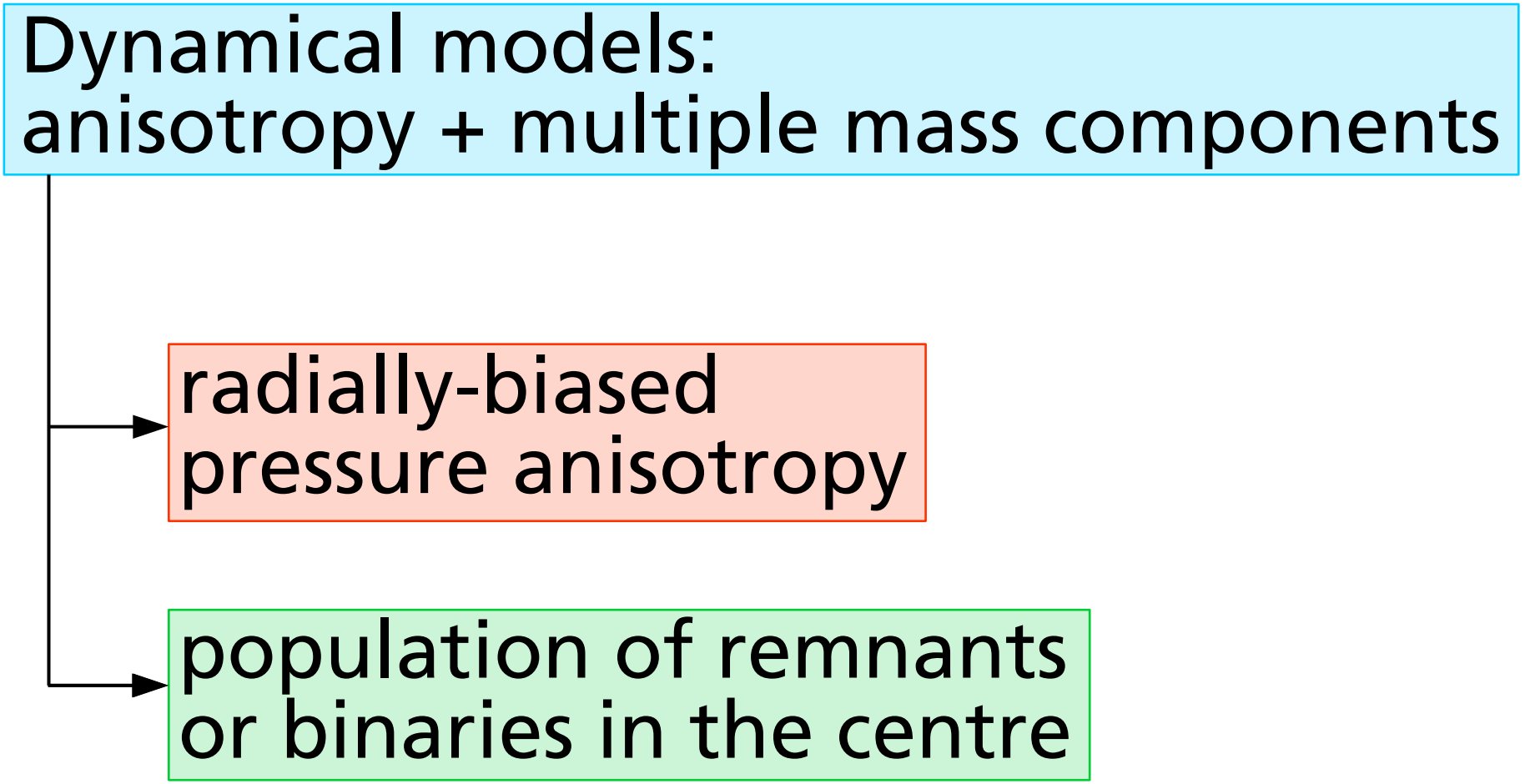
radially-biased pressure anisotropy



population of remnants or binaries in the centre



INVESTIGATING THE DEGENERACY



INVESTIGATING THE DEGENERACY

Dynamical models:
anisotropy + multiple mass components

DISTRIBUTION FUNCTION BASED MODELS

LIMEPY - **L**owered **I**sothermal **M**odel **E**xplorer in **PY**thon

$$f(E, J^2) = A \exp\left(-\frac{J^2}{2 r_a^2 s^2}\right) \mathrm{E}\left(\frac{\phi(r_t) - E}{s^2}; g\right)$$

$$E = \frac{v^2}{2} + \phi(r)$$

$$J^2 = |\mathbf{r} \times \mathbf{v}|^2 = r^2 v^2 \sin^2\theta$$

$$\mathrm{E}(x; g) = \begin{cases} e^x & g = 0 \\ e^x \dfrac{\gamma(g, x)}{\Gamma(g)} & g > 0 \end{cases}$$

Particular cases
(when $r_a \to \infty$):

- g = 0 → Woolley 1954
- g = 1 → King 1966
- g = 2 → Wilson 1975
  (non-rotating limit)

Davoust 1977
Gomez-Leyton & Velazquez 2014
Gieles & Zocchi 2015

LIMEPY is available online:
`https://github.com/mgieles/limepy`

DISTRIBUTION FUNCTION BASED MODELS

LIMEPY - Lowered Isothermal **M**odel **E**xplorer in **PY**thon

$$f(E, J^2) = A \exp\left(-\frac{J^2}{2 r_a^2 s^2}\right) \mathrm{E}\left(\frac{\phi(r_t) - E}{s^2}; g\right)$$

$$E = \frac{v^2}{2} + \phi(r)$$

$$J^2 = |\mathbf{r} \times \mathbf{v}|^2 = r^2 v^2 \sin^2\theta$$

$$\mathrm{E}(x; g) = \begin{cases} e^x & g = 0 \\ e^x \dfrac{\gamma(g, x)}{\Gamma(g)} & g > 0 \end{cases}$$

Model parameters:
concentration, truncation,
anisotropy radius

Physical scales: mass, radial scale (determined by A, s)

Davoust 1977
Gomez-Leyton & Velazquez 2014
Gieles & Zocchi 2015

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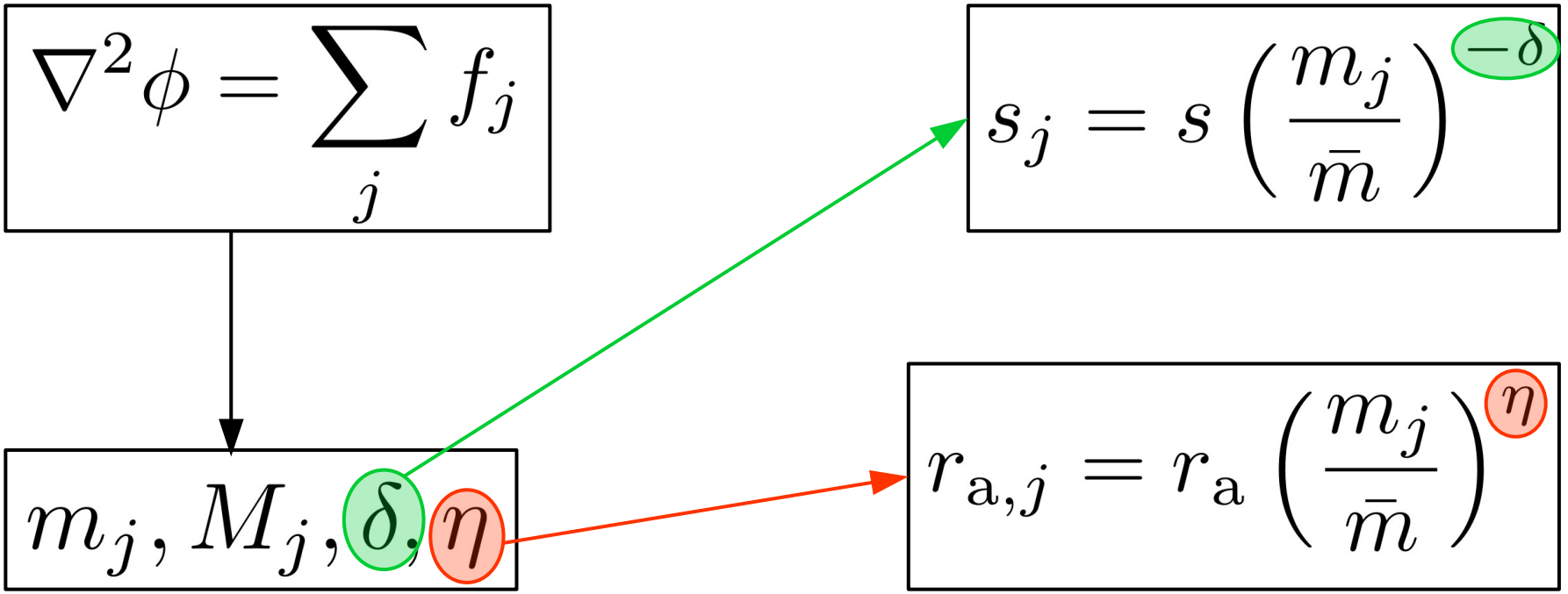
DISTRIBUTION FUNCTION BASED MODELS

LIMEPY - **L**owered **I**sothermal **M**odel **E**xplorer in **PY**thon

Multiple mass components



Da Costa & Freeman 1976
Gunn & Griffin 1979
Gieles & Zocchi 2015

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LIMEPY MODELS vs NUMERICAL SIMULATIONS

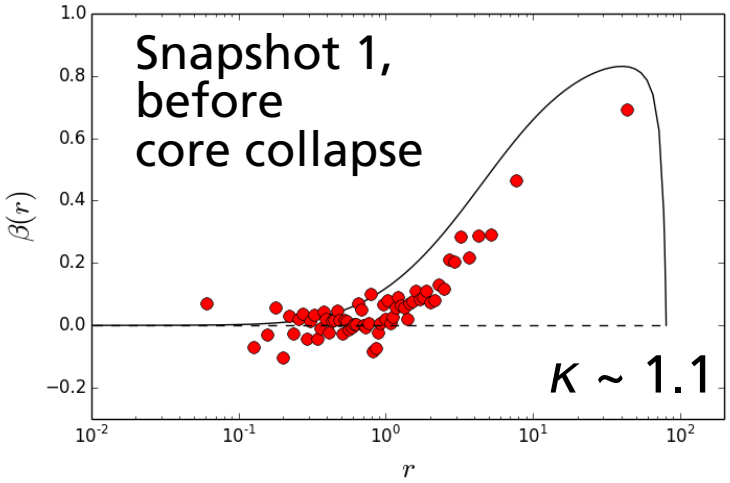
RADIAL ANISOTROPY

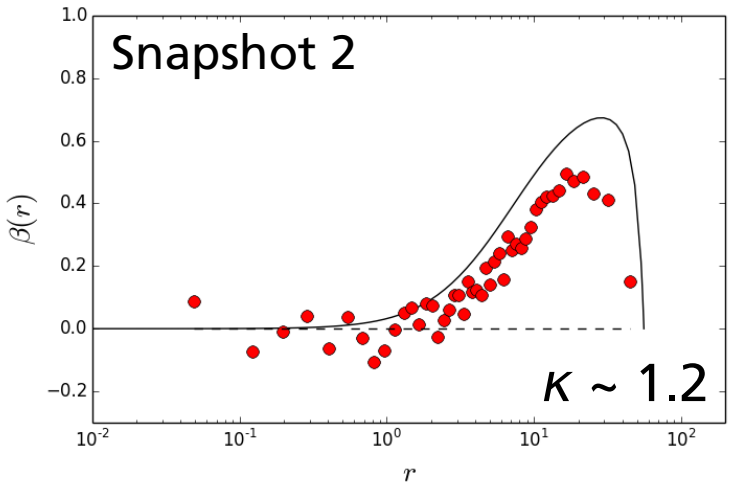
Anisotropy profile

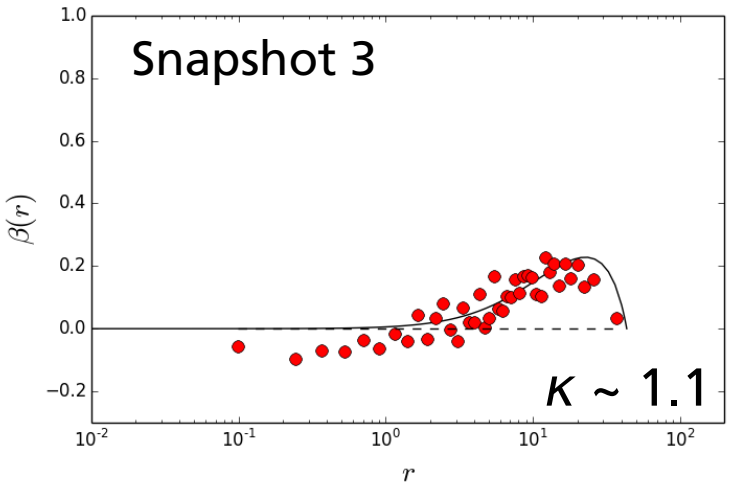
$$\beta = 1 - \frac{\sigma_t^2}{2\sigma_r^2}$$

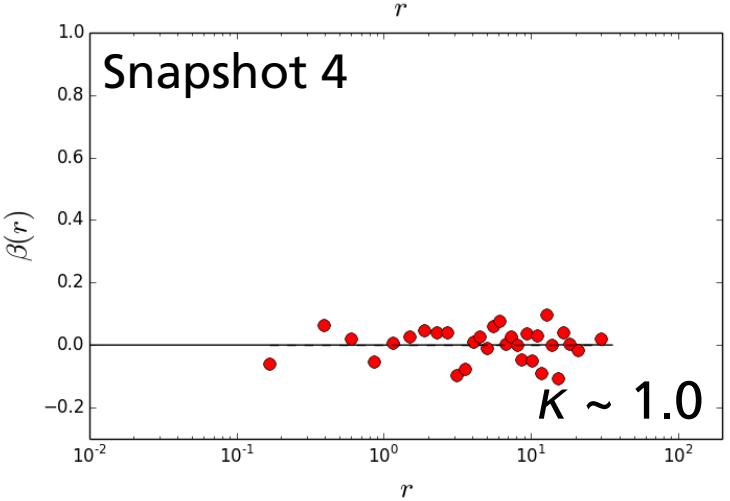
Anisotropy parameter

$$\kappa = \frac{2K_r}{K_t}$$





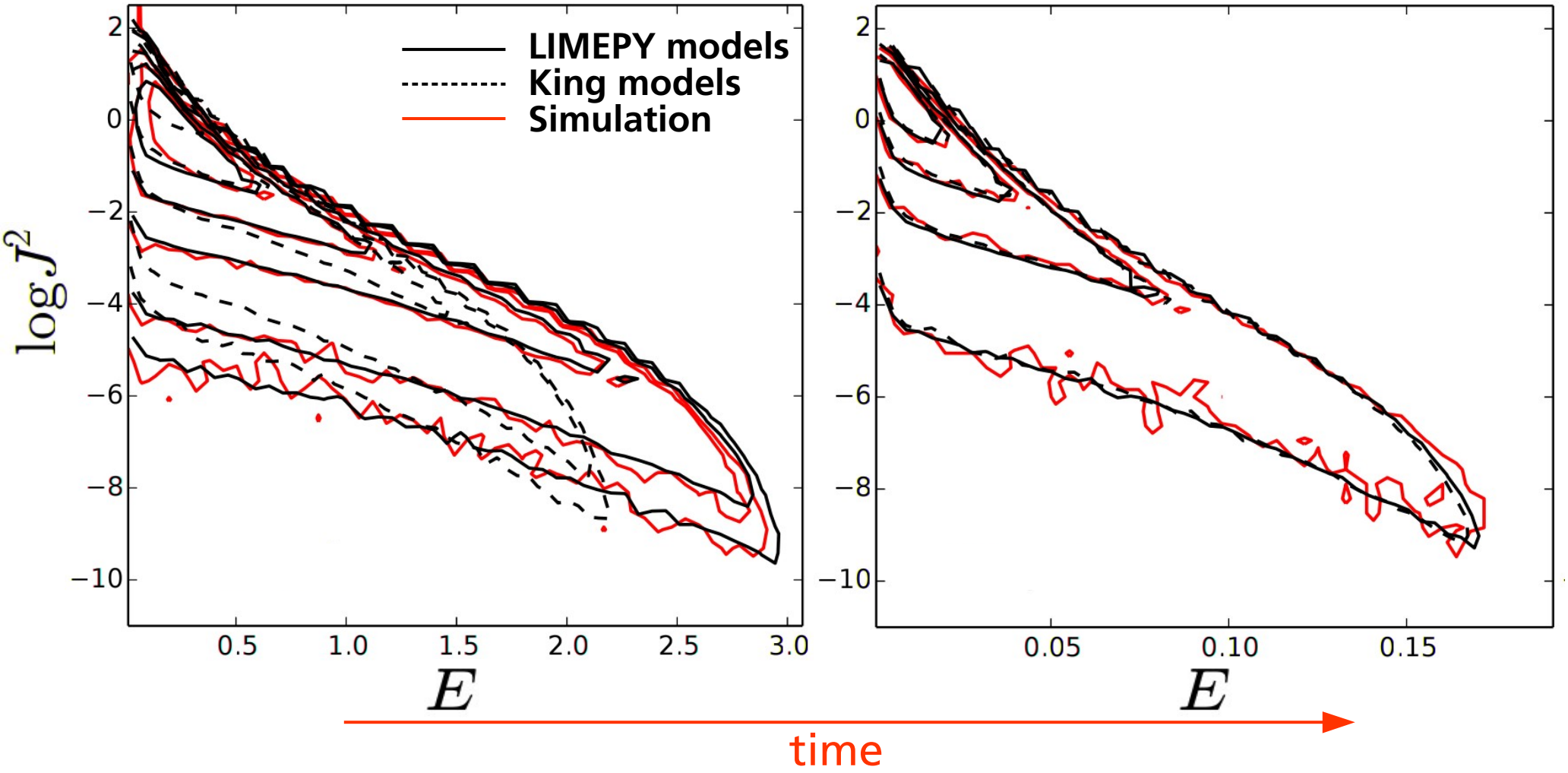




Zocchi et al., 2016

LIMEPY MODELS vs NUMERICAL SIMULATIONS

RADIAL ANISOTROPY

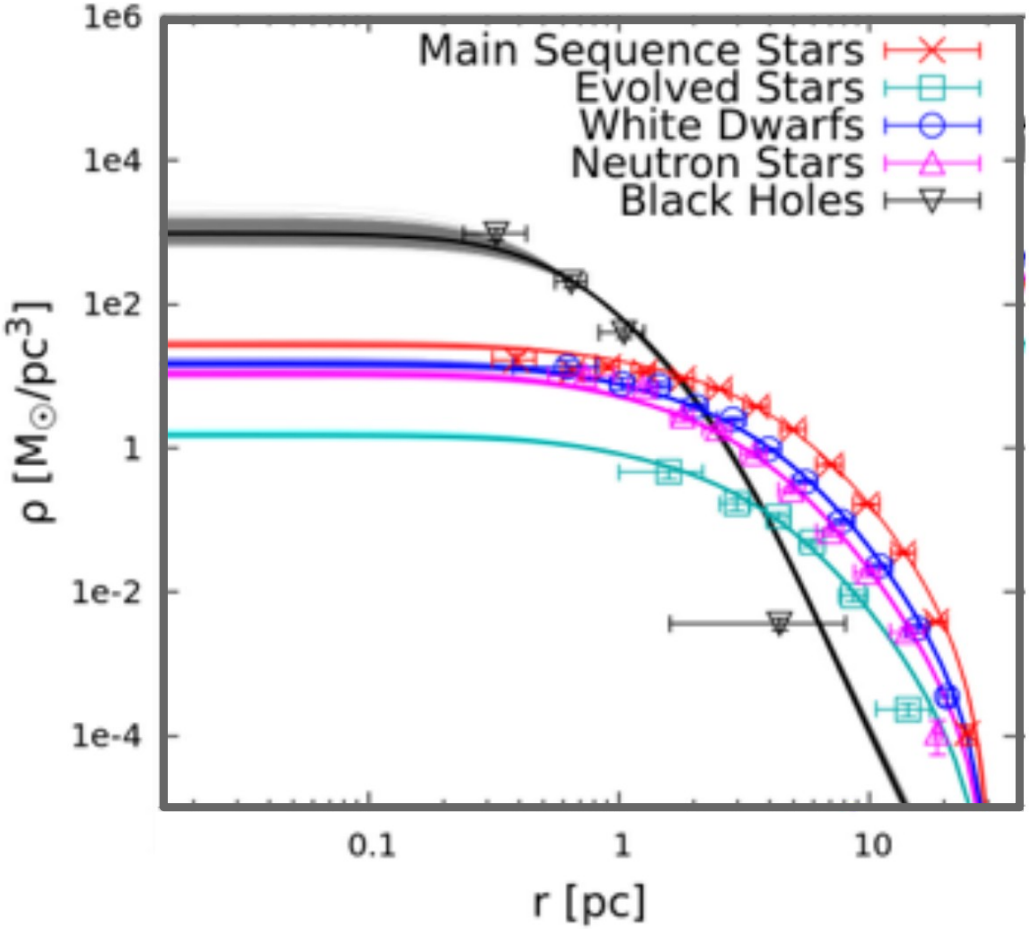


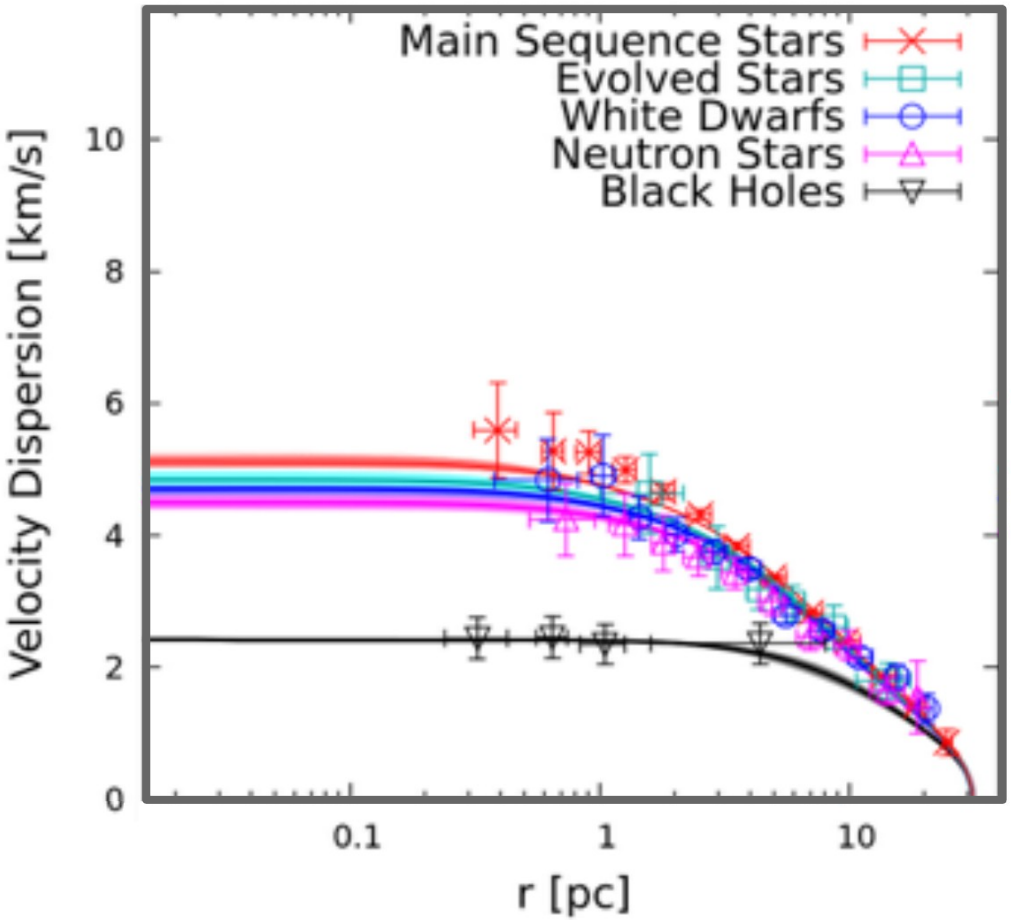
Zocchi et al., 2016

LIMEPY MODELS vs NUMERICAL SIMULATIONS

REMNANTS & MASS SEGREGATION

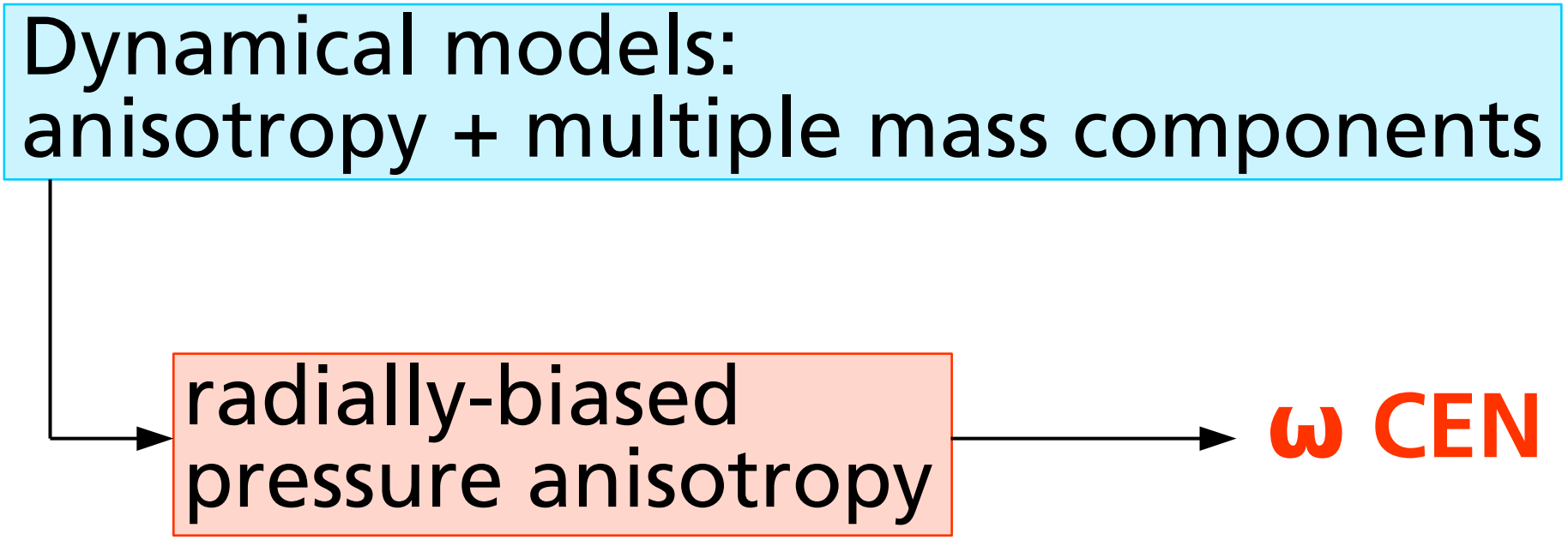
Mass function: multiple components of mass → Mass segregation





Peuten et al., in prep.

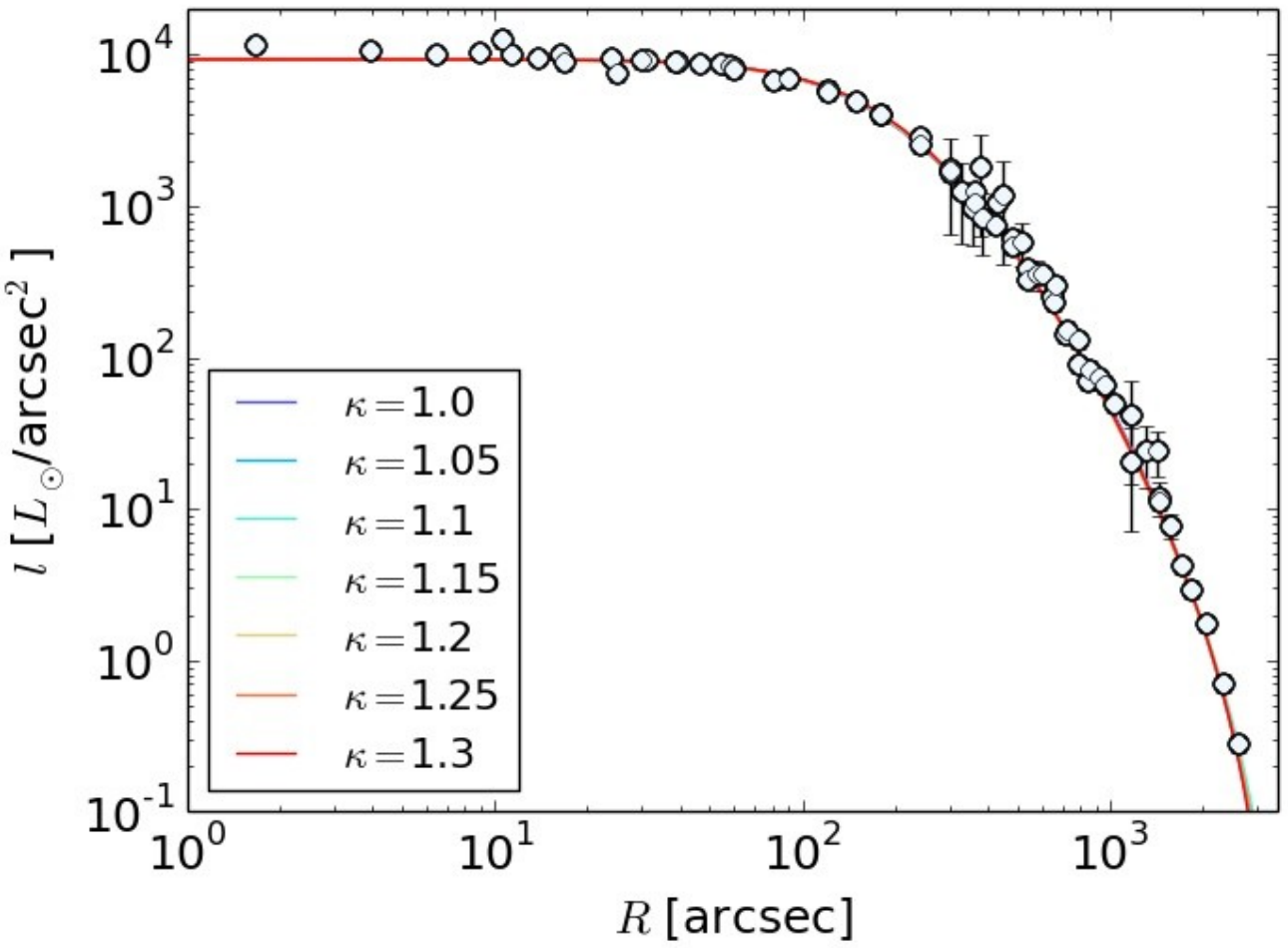
INVESTIGATING THE DEGENERACY



DYNAMICAL STUDY OF ω CEN

Zocchi et al., to be submitted

Surface brightness profile



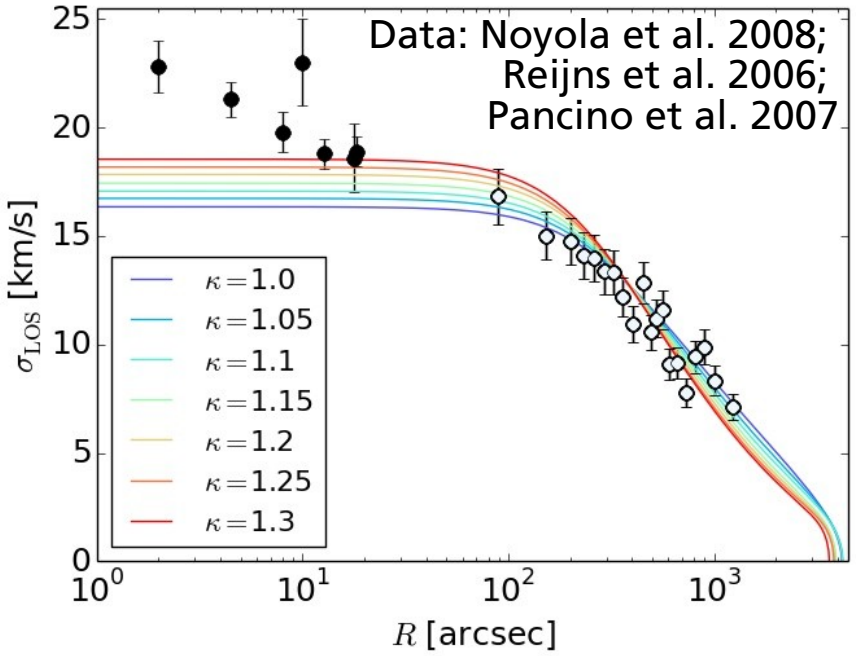
Data: Noyola et al. 2006; Trager, King, Djorgovski 1995

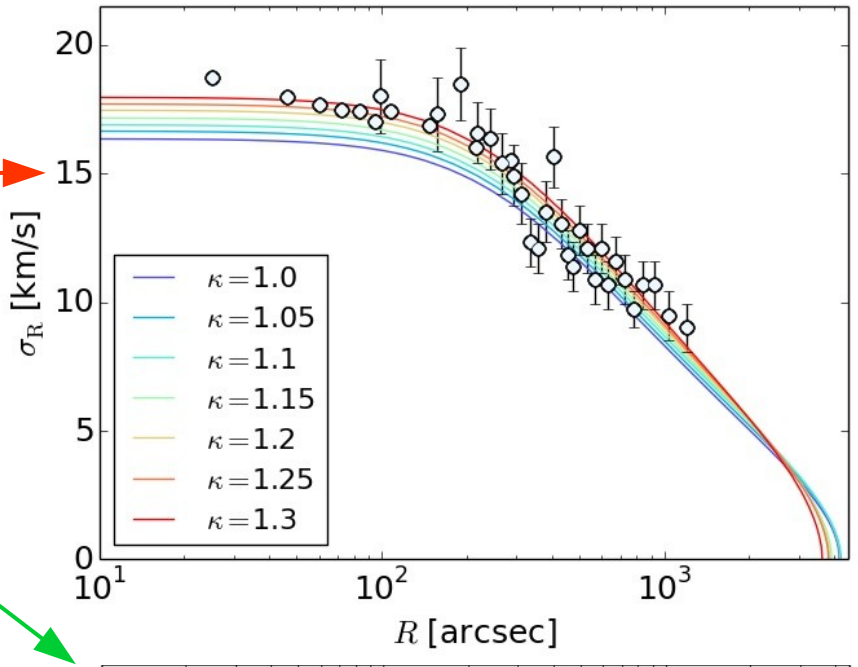
DYNAMICAL STUDY OF ω CEN

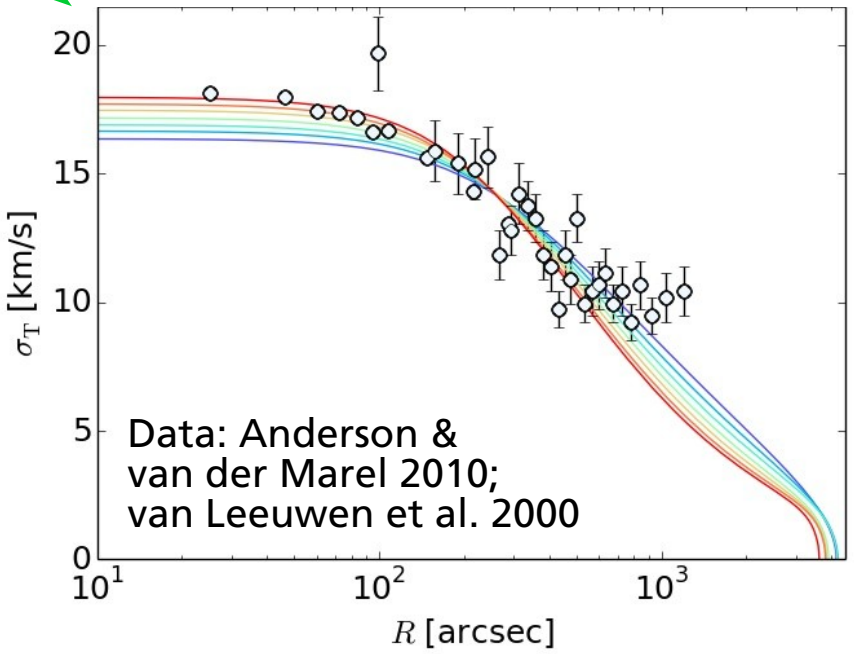
Zocchi et al., to be submitted

Proper motion data: radial and tangential velocity dispersion profiles

Line-of-sight velocity dispersion profile



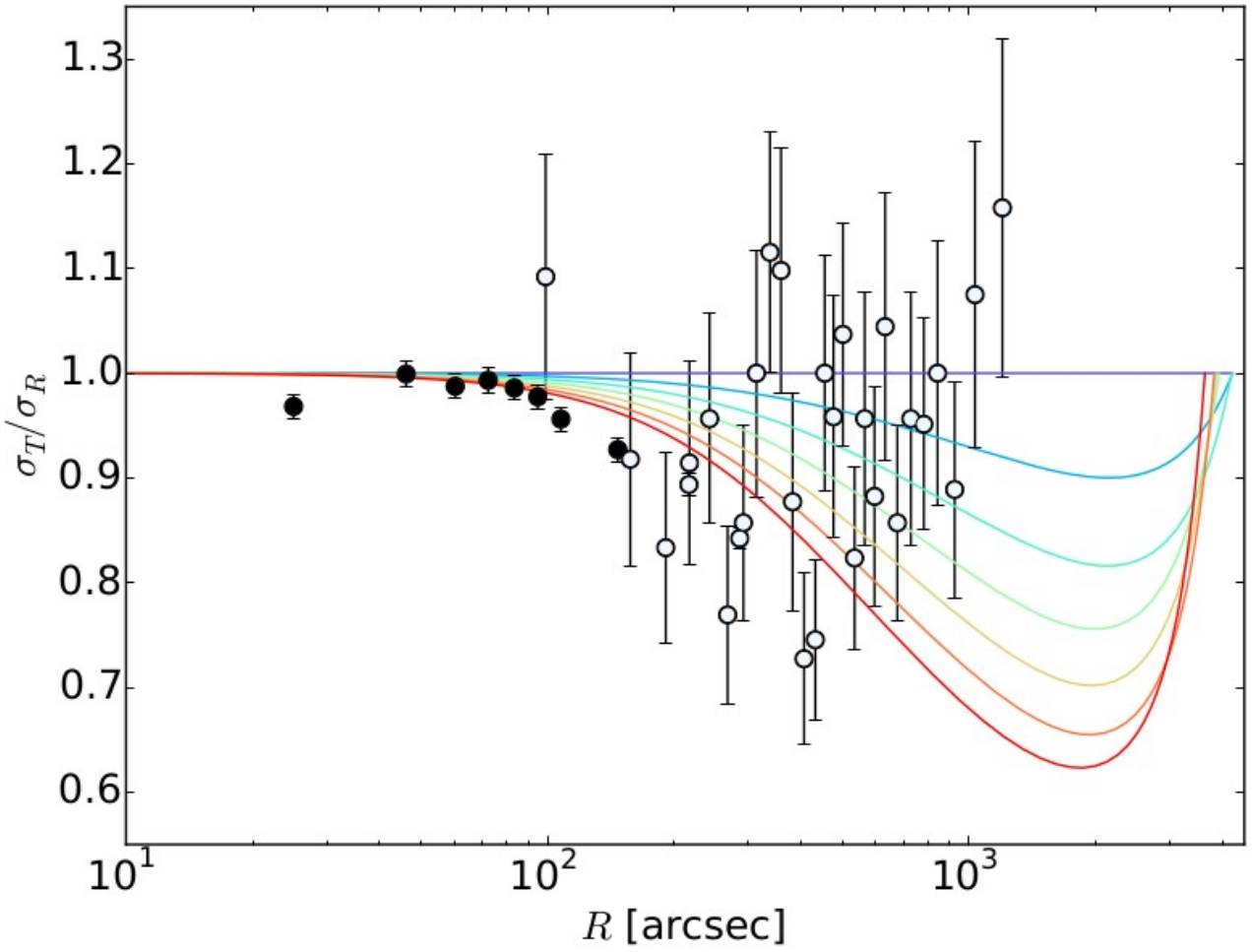




DYNAMICAL STUDY OF ω CEN

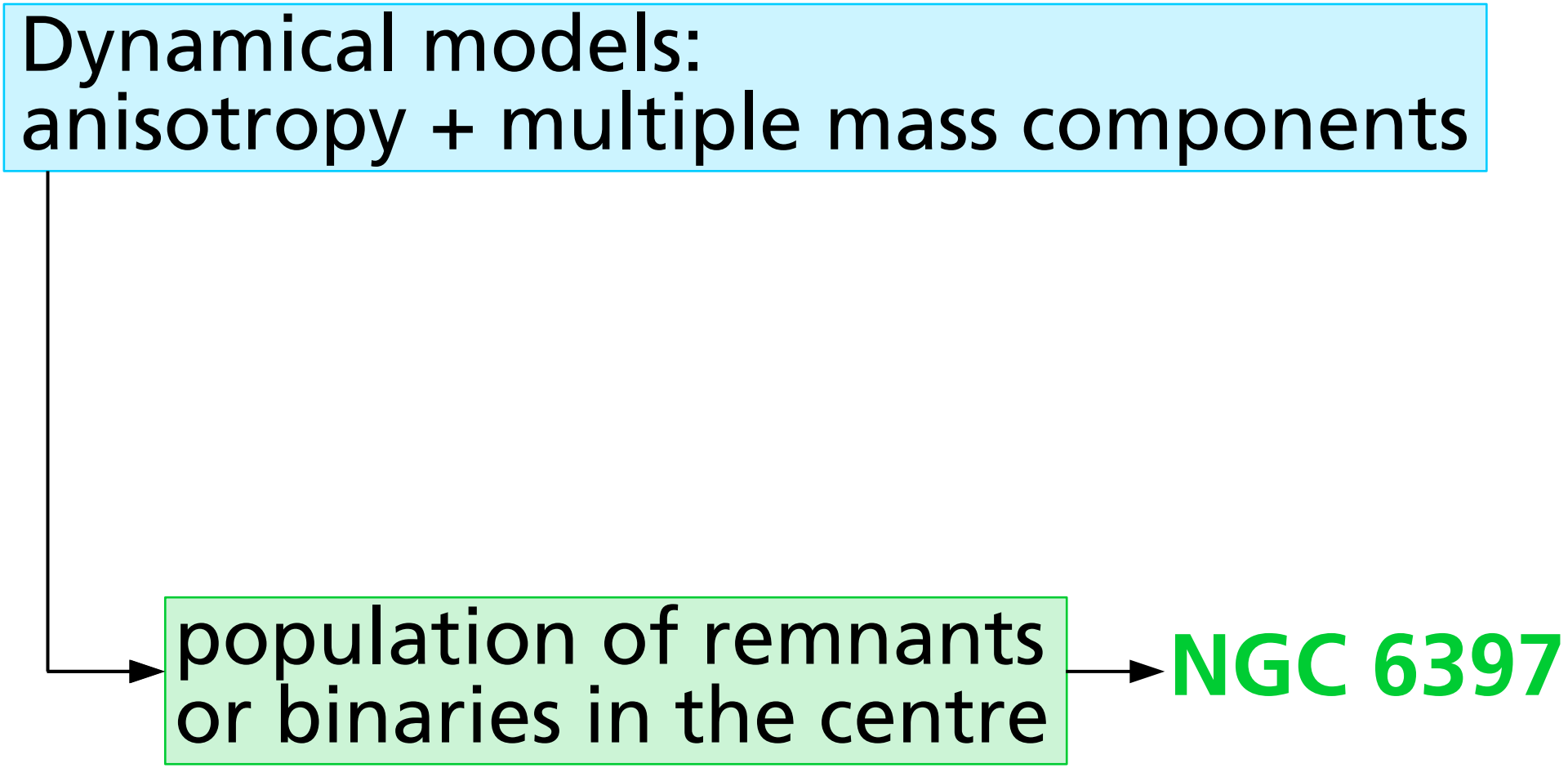
Zocchi et al., to be submitted

Anisotropy profile



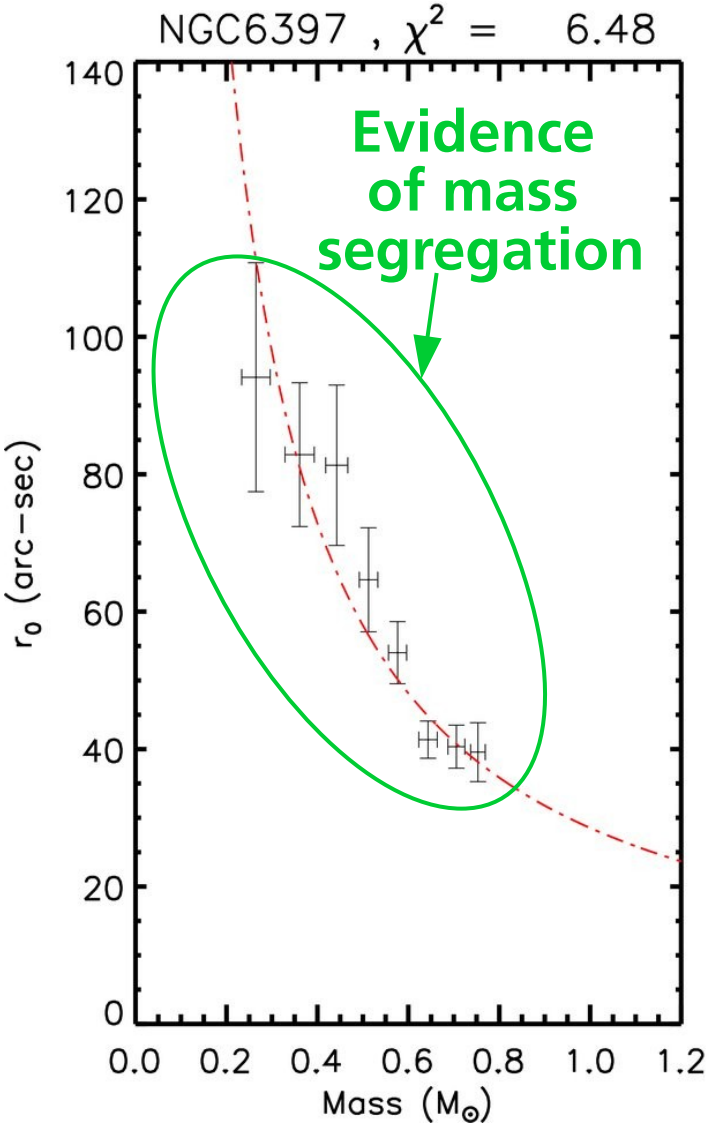
Data: Anderson & van der Marel 2010; van Leeuwen et al. 2000

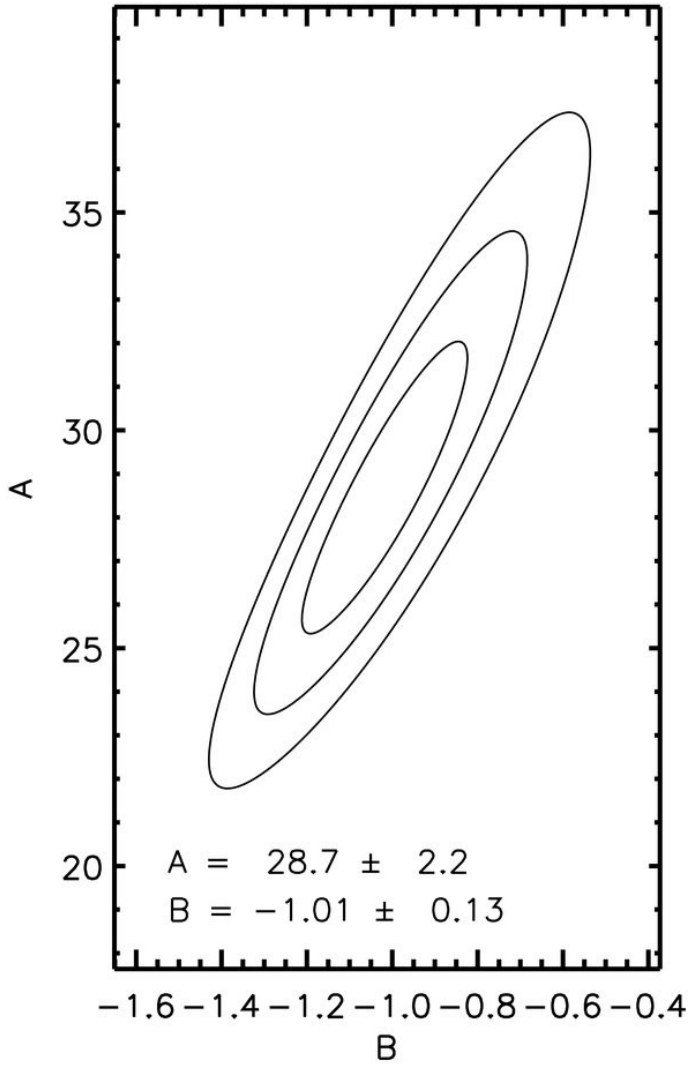
INVESTIGATING THE DEGENERACY



MASS SEGREGATION IN NGC 6397

Goldsbury, Heyl, & Richer 2013





DYNAMICAL STUDY OF NGC 6397

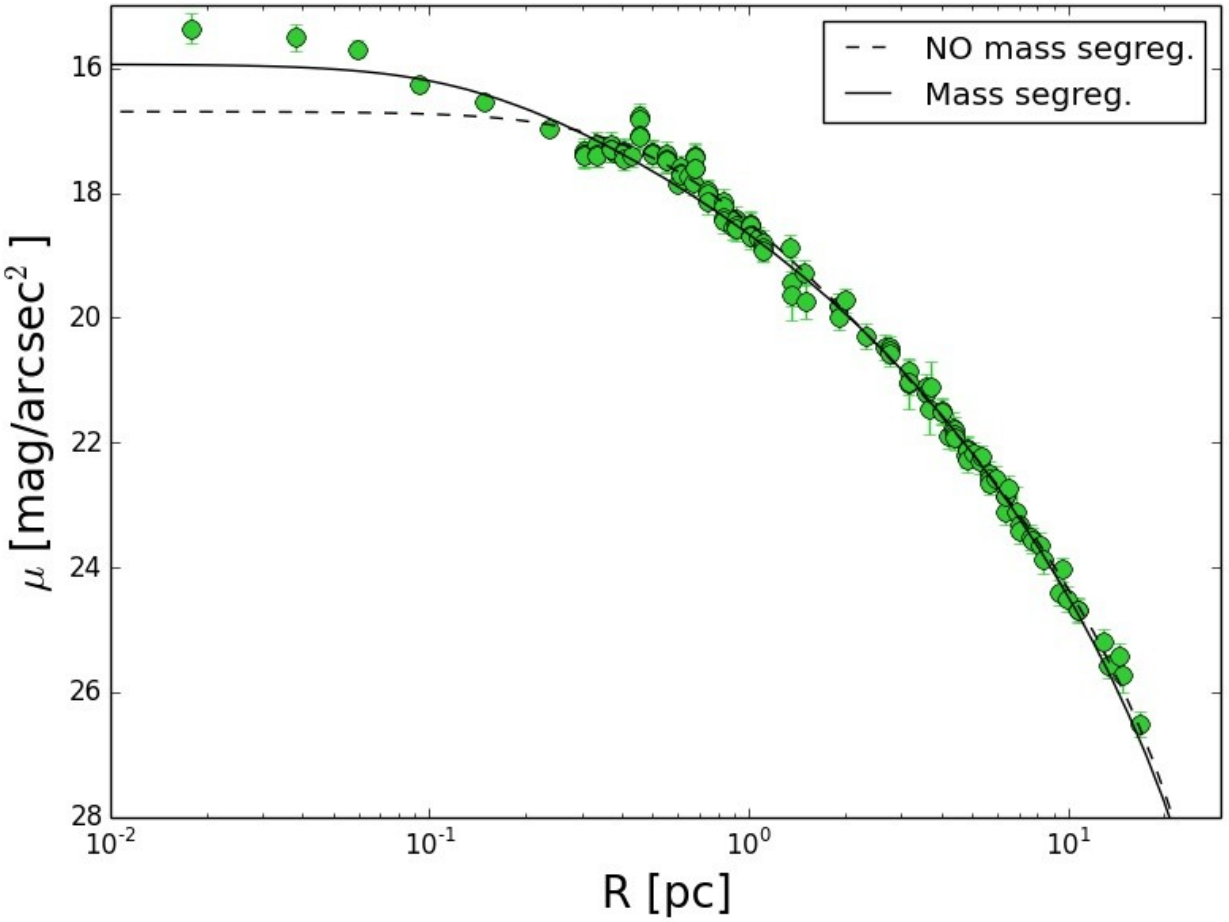
WORK IN PROGRESS!

- Isotropic multiple components LIMEPY models, with and without mass segregation
- Mass function:
  - Kroupa IMF between 0.08 and 100 solar masses
  - Age ~ 12.5 Gyr
  - Metallicity: Z = 0.0002
- No stellar mass black holes
- All neutron stars retained (no velocity kicks)
- Fitting parameters: W_0, g, M, r_h

DYNAMICAL STUDY OF NGC 6397

WORK IN PROGRESS!

Surface brightness profile

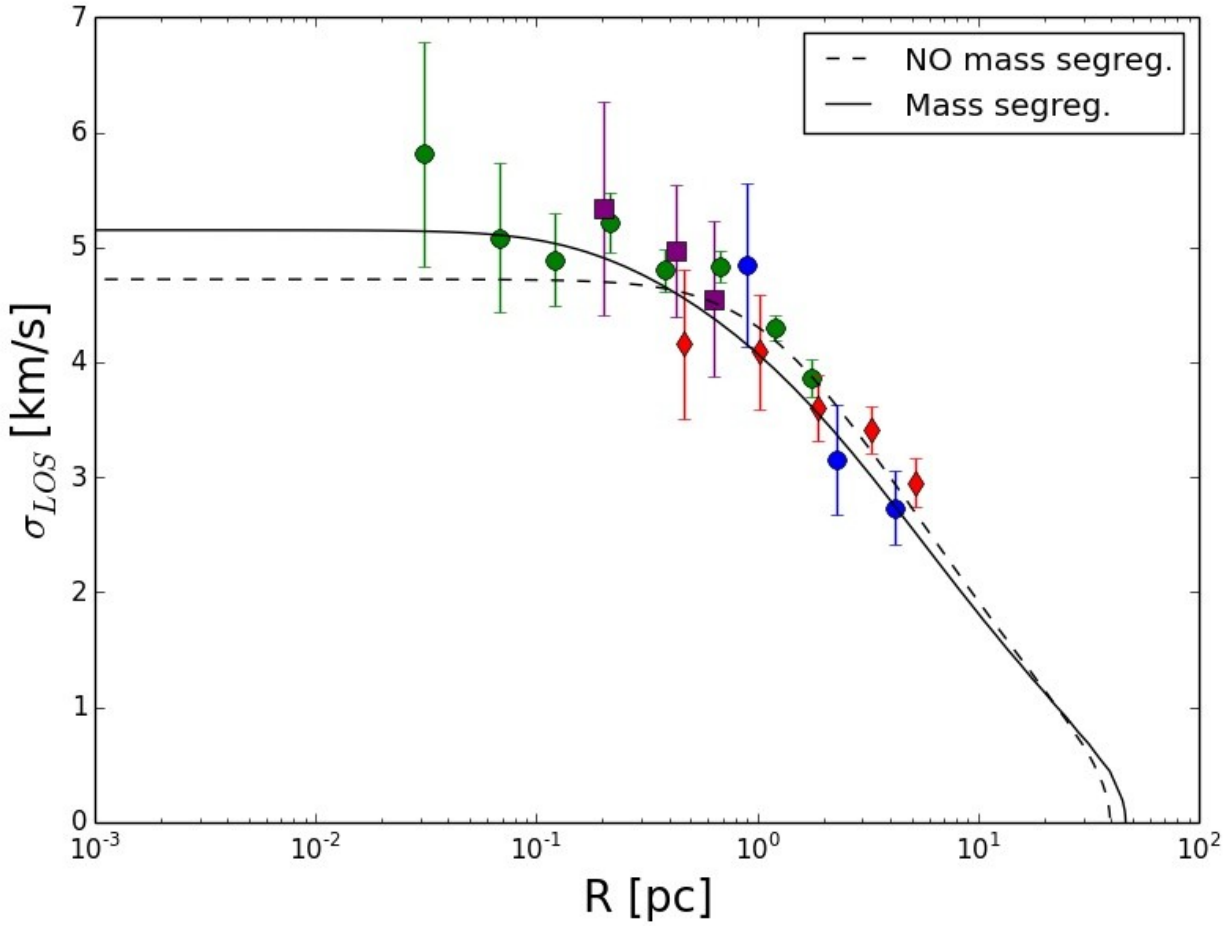


Data: Kamann et al. 2016; Trager, King, Djorgovski 1995

DYNAMICAL STUDY OF NGC 6397

WORK IN PROGRESS!

Velocity dispersion profile



Data: Kamann et al. 2016; Gebhardt et al. 1995;
Lind et al. 2009; Carretta et al. 2009

CONCLUSIONS

- Pressure anisotropy or the presence of a population of remnants in the centre of clusters cause a rise in the line-of-sight velocity dispersion of globular clusters. This creates a degeneracy with the rise that is expected when an IMBH is present at the centre of the cluster.

- **Anisotropic dynamical models** (no rotation, stars all with the same mass, no intermediate-mass black hole) describe reasonably well the surface brightness and (LOS and PM) velocity dispersion profiles of **ω Cen**.

- **Multi-mass isotropic models** (mass segregation, no rotation, no intermediate-mass black hole) describe reasonably well the surface brightness and velocity dispersion profiles of **NGC 6397**. [In progress!]