Stellar Dynamics and Structure of Galaxies

Introduction. Spherically symmetric objects

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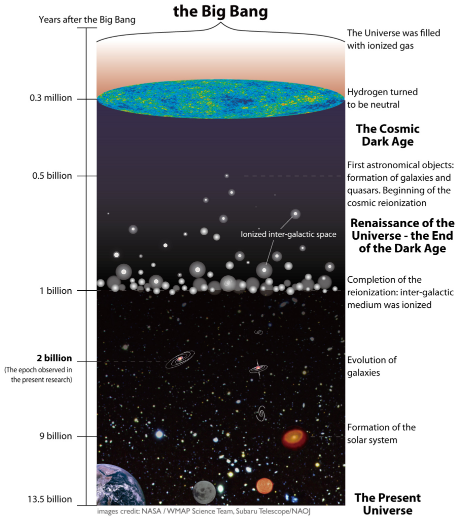
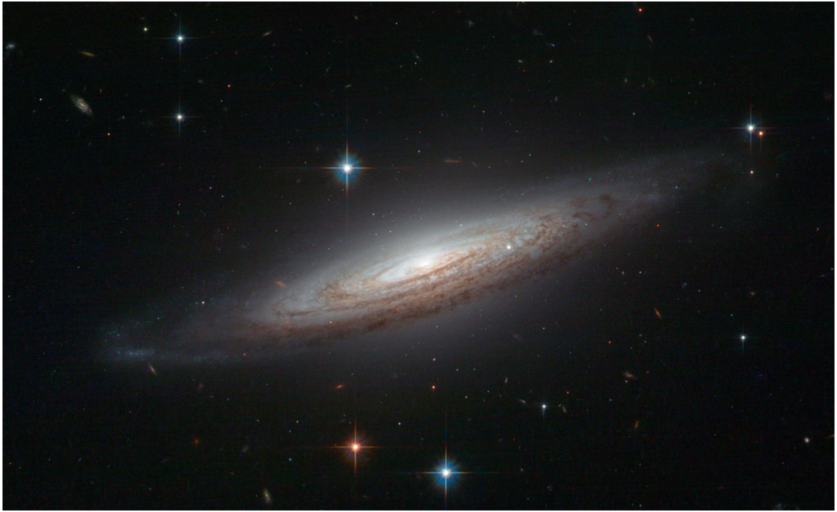
Outline I

Why study galaxies?



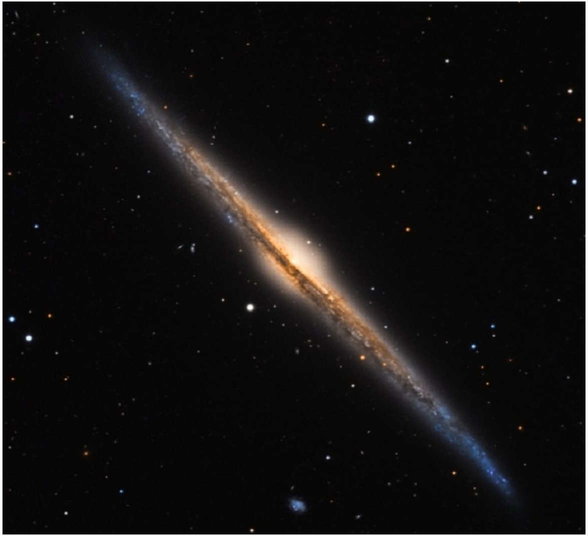
Cosmic Timeline

Stellar Dynamics = Structure of Galaxies



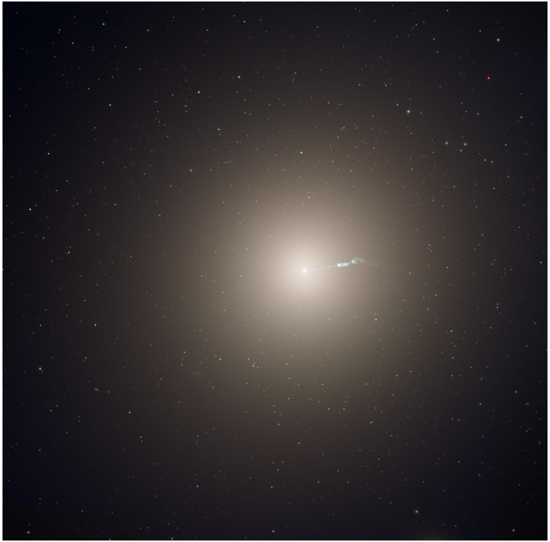
NGC 634

Stellar Dynamics = Structure of Galaxies



NGC 4565

Stellar Dynamics = Structure of Galaxies



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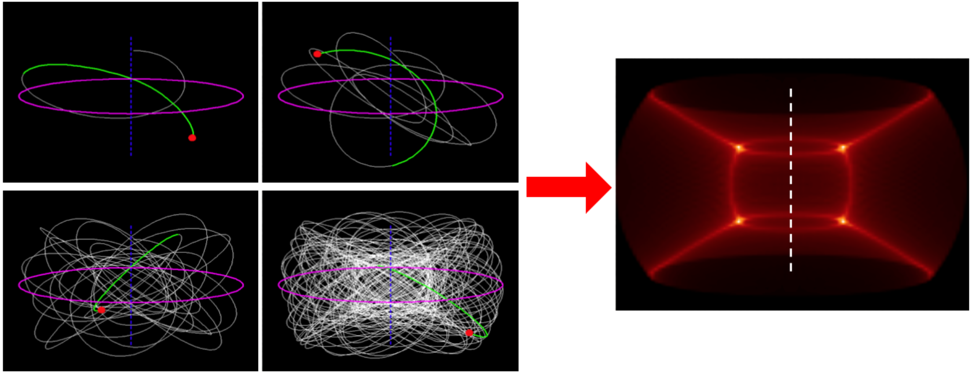
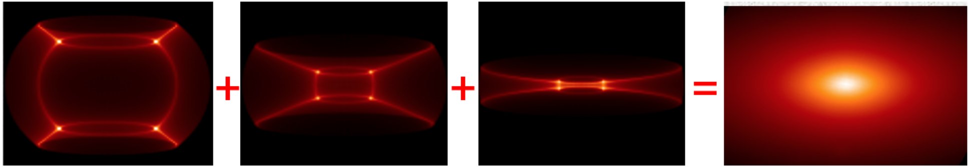
Stellar Dynamics = Structure of Galaxies



Orbits in axisymmetric potential. From Cappellari et al 2004

Stellar Dynamics = Structure of Galaxies



Observed light and velocity distribution is nothing but the superposition of stellar orbits

Why Study Galaxies?

Because they are beautiful!

- What is the mass distribution?
- On what orbits do stars, gas, dark matter, globular clusters move?
- How much mass contributed by each component?
- What can we learn about the formation and evolution?

With the hope to solve the following conundrums:

- Nature of the dark matter particle, interaction between dark matter and ordinary matter, fomatiom of the first stars and galaxies, formation of the first black holes, black hole growth, jets, element abundance evolution

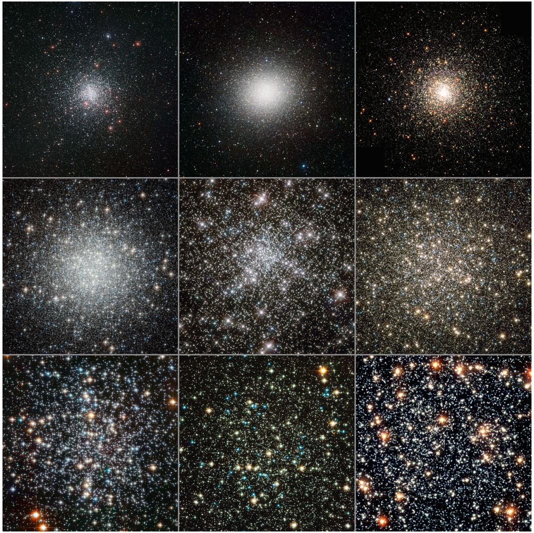
Collisional and collisionless

Stars and gas

- Around solar radius, the typical distance between two stars is 10^{19} cm.
- What about the galaxy centre?
- Gas can shock. Gas can radiate.
- Cooling gas will loose energy, hence change the shape of the distribution.

Globular cluster properties

- Round, smooth distribution of stars (assume spherical)
- Population II (old) stars
- 10^4 - 10^6 stars in each
- Ages $\sim 10^{10}$ years (from stellar evolution models and isochrone fitting).
- Traditionally measure surface brightness as a function of R i.e. $\mu(R)$, or (more recently) use high resolution HST images to count stars $N(R)$.



Top row: Messier 4 (ESO), Omega Centauri (ESO), Messier 80 (Hubble)
Middle row: Messier 53 (Hubble), NGC 6752 (Hubble), Messier 13 (Hubble)
Bottom row: Messier 4 (Hubble), NGC 288 (Hubble), 47 Tucanae (Hubble)

Globular cluster properties

Density profile

We want star mass density $\rho(r)$ as a function of radius:

- Use M/L (~ 2 solar units) or star masses M_* to convert $\mu(R)$ or $N(R)$ to surface mass density $\Sigma(R)$.
- Assume spherical symmetry $\Sigma(R) \rightarrow \rho(r)$

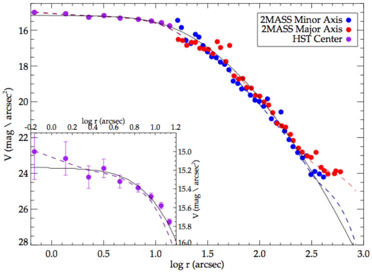


Fig. 4. The surface brightness profile of NGC 2808. The red and the blue circles mark the measurements from the 2MASS image along the major and minor axis, respectively, as well as their MGE parametrization (dashed lines). The profile obtained from the HST star catalog is shown in purple. Overplotted is the profile obtained by Trager et al. (1995) with a solid black line.

Globular cluster properties

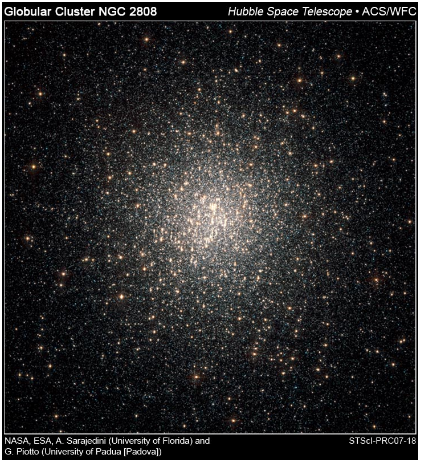
Important radii

- At **core radius** $\mu(R_c) = \frac{1}{2}\mu(0)$, $R_c \sim 1.5$ pc. ρ constant for $r < R_c$
- Median radius, typical radius, characteristic radius: contains **half the light** (2D). $R_h \sim 10$ pc.
- As we approach **tidal radius**: $\mu \to 0$, the "edge" of the cluster, is at $r_t \sim 50$ pc.

Globular cluster properties

Masses

- Total mass $M \lesssim 1 \times 10^4 \mathrm{M}_\odot$
- Star masses up to 0.8 $\mathrm{M}_\odot$
- Core density $\rho_c = \rho(0) \sim 8 \times 10^4\ \mathrm{M}_\odot\ \mathrm{pc}^{-3}$
- One-dimensional central velocity dispersion $\sigma_r \equiv \sqrt{\overline{v_r^2}} \sim 13\ \mathrm{km\ s}^{-1}$ (ranges from 2 - 15 km s^{-1})



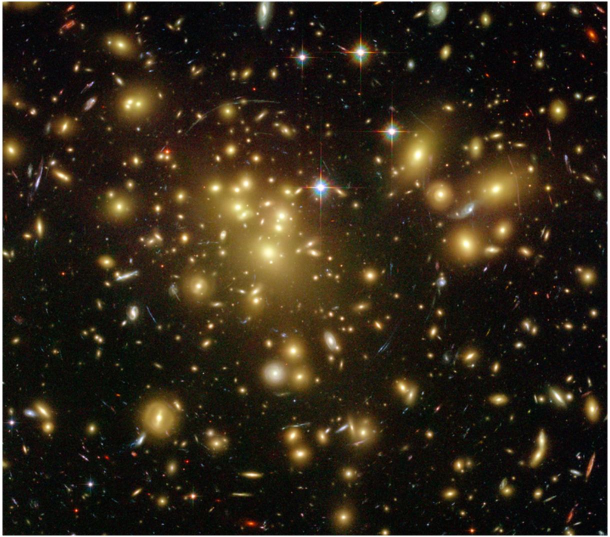
Open clusters

NGC 3603

Open cluster properties

- $N \sim 10^2$ - 10^3 stars
- Age $\lesssim 10^8$ years $\Rightarrow$ either all formed recently or form and disperse continually.
- $R_c \sim 1$ pc
- $R_h \sim 2$ pc
- $r_t \sim 10$ pc, because of stronger gravity in the disk of the Galaxy, and lower cluster mass.
- Mass $\sim 250\ \mathrm{M}_\odot$
- $M/L \sim 1$ (solar units)
- $\rho_c \sim 100\ \mathrm{M}_\odot\ \mathrm{pc}^{-3}$ (cf solar neighbourhood $\bar{\rho} = 0.05\ \mathrm{M}_\odot\ \mathrm{pc}^{-3}$).
- $\sigma_r = \sqrt{\overline{v_r^2}} \sim 1\ \mathrm{km\ s}^{-1}$ (system assumed approximately isothermal).

Galaxy clusters



Abell 1689

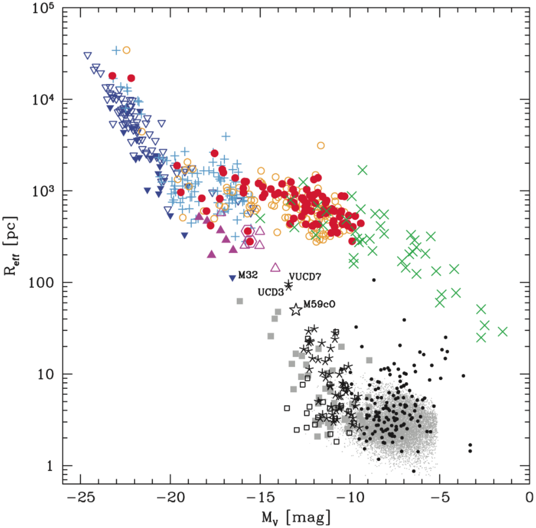
Properties of galaxy clusters

- Large range of N, and wide spread of M, but typically $N \sim 100$ galaxies, and total masses $\sim 10^{15}$ $M_\odot$ (much of the mass is not visible).
- $R_c \sim 250$ kpc
- $R_h \sim 3$ Mpc
- $\sigma_r \sim 800$ km s^{-1}
- Crossing time

$$t_{\rm cross} \sim R_h/\sigma_r \sim 10^9 \left(\frac{R_h}{1 \text{ Mpc}}\right) \left(\frac{\sigma_r}{10^3 \text{ km s}^-1}\right)^{-1}$$

- Age $\lesssim 13.7 \times 10^9$ yr (age of the universe) $\Rightarrow$ dynamically young, often still forming, collapsing for the first time.

Comparison of hot stellar systems



Comparison of hot stellar systems