Structural Evolution of Early-Type Galaxies

Modelling deprojected morphology

Chang et. al (2013)

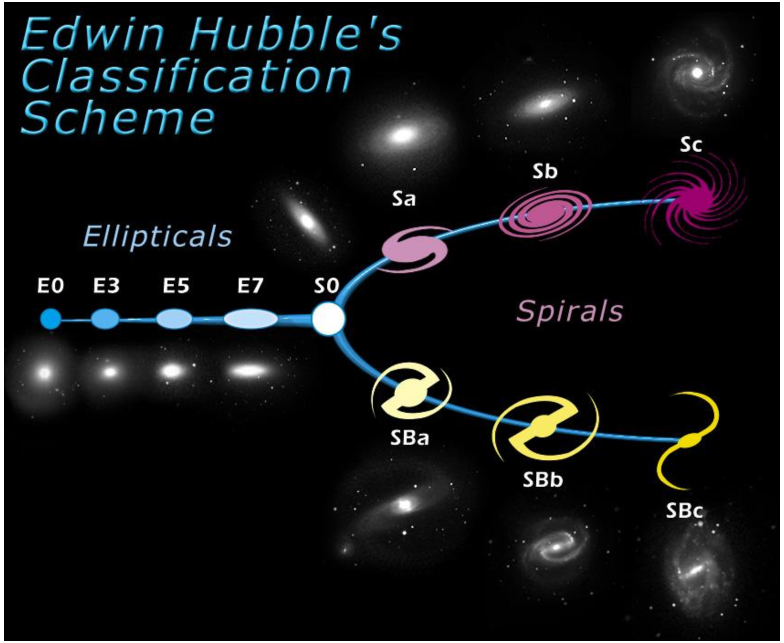
“Projected axis ratio measurements of 880 early-type galaxies at redshifts $1 < z < 2.5$ selected from CANDELS are used to reconstruct and model their intrinsic shapes.”

“[...] even at a fixed mass, the projected axis ratio distributions cannot be explained by the random projection of a set of galaxies with very similar intrinsic shapes. However, a two-population model for the intrinsic shapes, consisting of a triaxial, fairly round population, combined with a flat ($c/a \sim 0.3$) oblate population, adequately describes the projected axis ratio distributions of both present-day and $z > 1$ early-type galaxies.”

- CANDELS (Cosmic Assembly Near-infrared Deep Extragalactic Legacy Survey) is a HST survey designed to study the first third of galactic evolution

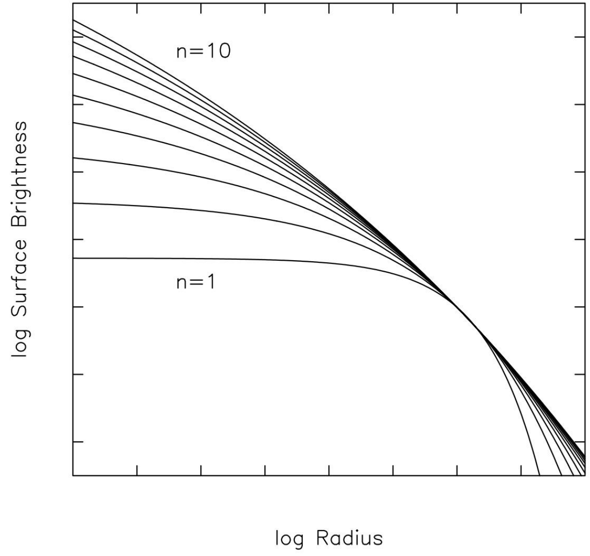
Hubble's Classification

- We can broadly classify galaxies into early and late types
- For our modelling purposes, ellipticals are generalized to be ellipsoids of varying axial ratios



Selecting Data

- The data is selected from HST CANDELS catalogs
- Early type galaxies up to z of 2.5 selected
- The structural parameters (radii, Sersic indices, and projected axial ratios) are taken from Van der Wel et al. (2012), who fit Sersic profiles algorithmically to individual galaxies



$$\ln\ I(R) = \ln\ I_0 - kR^{1/n}$$

Binning the Data

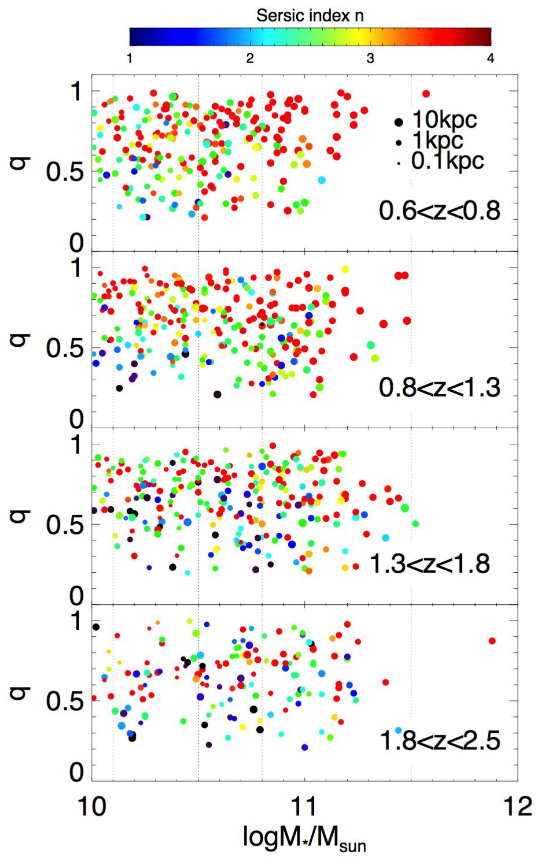
- Data is binned by stellar mass and redshift
- Only data with “good” flags from the GALFIT routine are accepted

TABLE 1
SAMPLE SIZES

$\log(M_*/M_\odot)$	10.1 – 11.5	10.8 – 11.5	10.5 – 10.8	10.1 – 10.5
Redshift	Numbers			
SDSS	32842	13640	13991	5211
H12	1321	384	475	462
$1 < z < 2.5$	569	197	168	204
$0.6 < z < 0.8$	220	47	67	106
$0.8 < z < 1.3$	256	78	66	112
$1.3 < z < 1.8$	244	88	71	85
$1.8 < z < 2.5$	147	55	47	45

Evolution of Projected Axis Ratios

- High mass early type galaxies are generally rounder with higher Sersic indices than low mass ones, but this trend weakens around *z = 2*
- At all redshifts, flatter galaxies have lower Sersic indices.
- This indicates that the observed axial ratios are not only the result of different viewing angles.



Defining a Model

$$m^2 = x^2/a^2 + y^2/b^2 + z^2/c^2$$

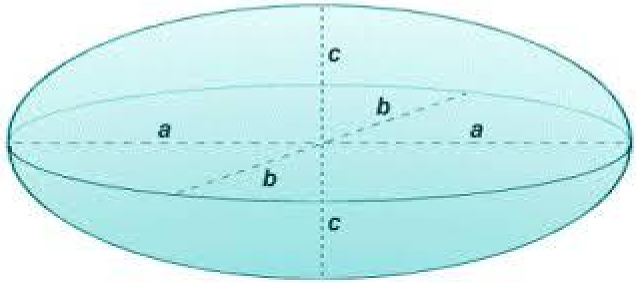
- Assume early type ellipticals can be classified as ellipsoids with differing axial ratios
- We can also define ellipticity and triaxiality parameters:

$$\beta = b/a$$

$$\gamma = c/a$$

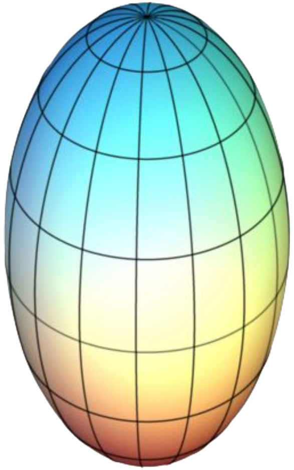
$$E = (1 - \gamma) \tag{1}$$

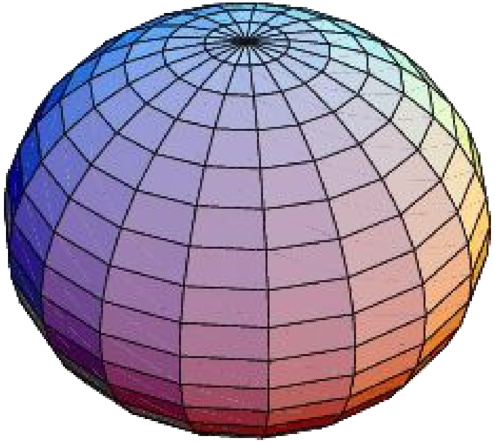
$$T = \frac{(1 - \beta^2)}{(1 - \gamma^2)} \tag{2}$$



Prolate and Oblate Spheroids

- Spherical ($A \sim B \sim C$)
- Prolate - ($A > B \sim C$)
- Oblate - ($A \sim B > C$)





Analytically Approximate the Intrinsic Axis Ratio Distribution

- According to Fall & Frenk (1983):

$$\psi_O(\gamma) = \frac{2}{\pi}\sqrt{1-\gamma^2}\frac{d}{d\gamma}\int_0^q \frac{\phi_O(q)dq}{\sqrt{\gamma^2 - q^2}} \qquad (1)$$

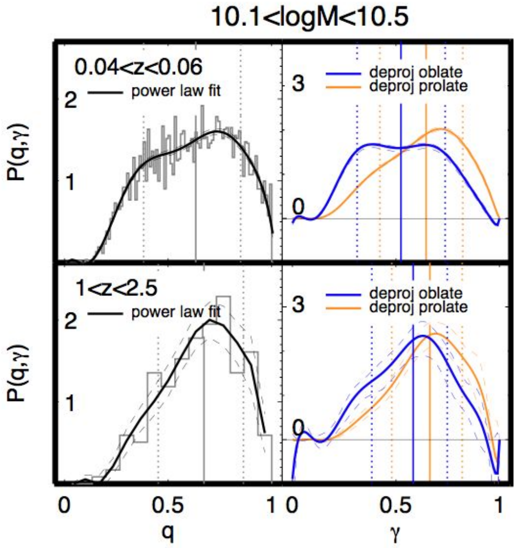
$$\psi_P(\gamma) = \frac{2}{\pi}\frac{\sqrt{1-\gamma^2}}{\gamma^2}\frac{d}{d\gamma}\int_0^q \frac{\phi_P(q)q^3dq}{\sqrt{\gamma^2 - q^2}} \qquad (2)$$

- Where ϕ is the distribution of projected axis ratios
- These equations can be rewritten analytically as:

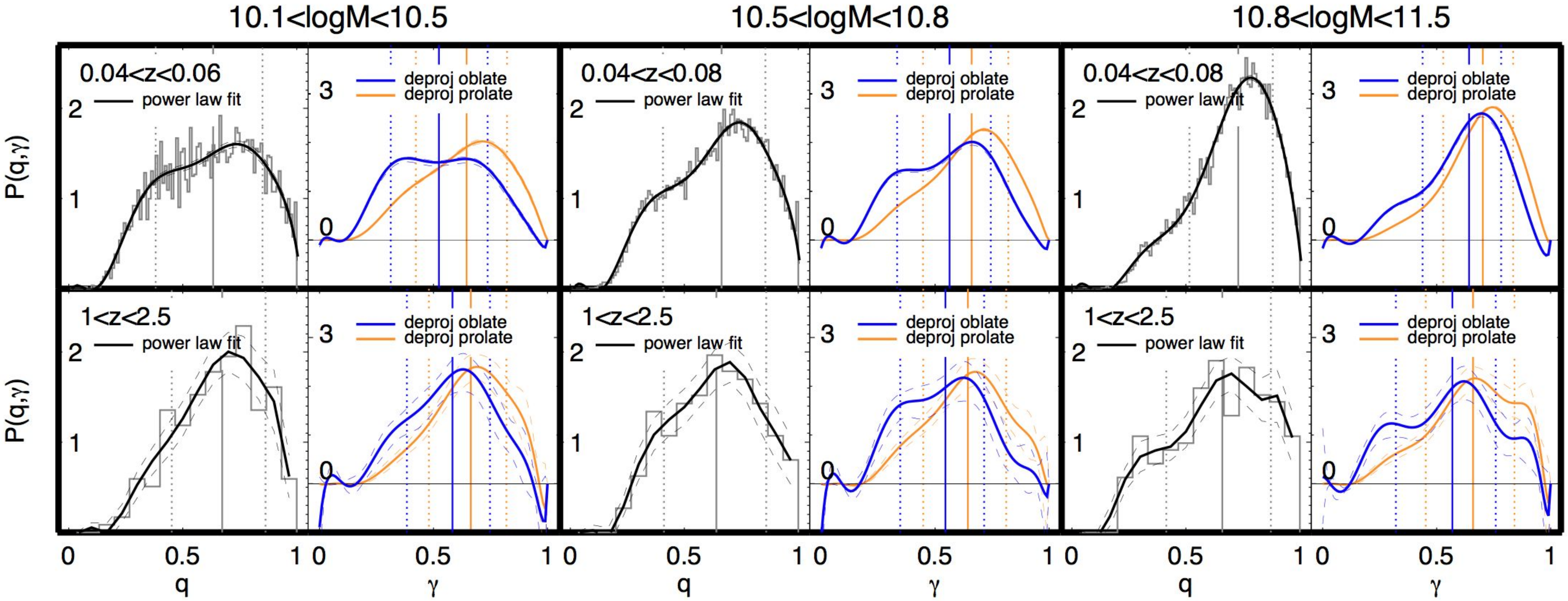
$$\psi_O(\gamma) = \frac{2\gamma^{m-1}\sqrt{1-\lambda^2}}{B(0.5m, 1.5)} \qquad (1)$$

$$\psi_P(\gamma) = \frac{2\gamma^{m}\sqrt{1-\lambda^2}}{B(0.5m+0.5, 1.5)} \qquad (2)$$

- Where *B(x,y)* is the beta function



“Deprojecting” the Projected Distribution



Projected Axial Ratios

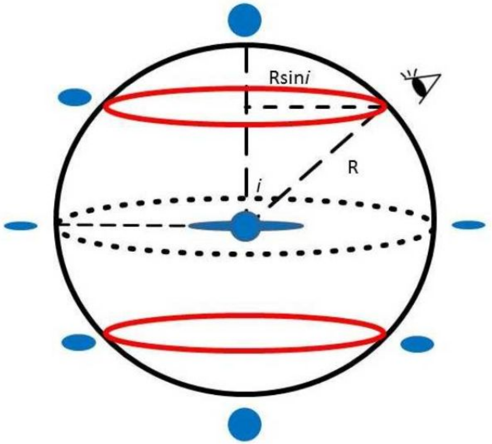
- The projected axial ratio, *q*, we observe depends on the viewing angles (Θ, ϕ) and also the unknown 3D axial ratio.
- If we know the axis lengths we can calculate *q* as follows:

$$A = \frac{\cos^2\theta}{\gamma^2}\left(\sin^2\theta + \frac{\cos^2\phi}{\beta^2}\right) + \frac{\sin^2\theta}{\beta^2} \quad (1)$$

$$B = \cos\theta \sin 2\theta \left(1 - \frac{1}{\beta^2}\right)\frac{1}{\gamma^2} \quad (2)$$

$$C = \left(\frac{\sin^2\phi}{\beta^2} + \cos^2\phi\right)\frac{1}{\gamma^2} \quad (3)$$

$$q(\theta,\phi;\beta,\gamma) = \sqrt{\frac{A + C - \sqrt{(A-C)^2 + B^2}}{A + C + \sqrt{(A-C)^2 + B^2}}} \quad (4)$$



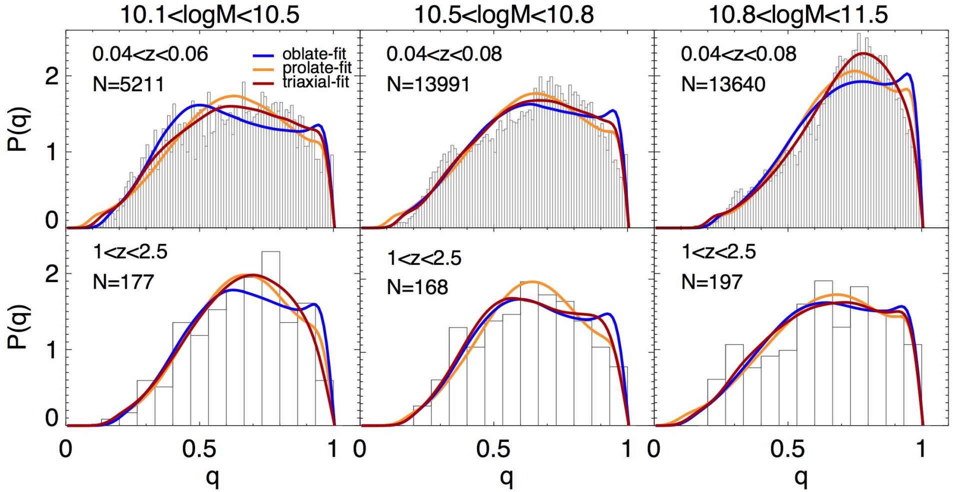
$\beta = b/a$

$\gamma = c/a$

Numerical Reconstruction of Projected Distribution

- Chang et al. assume Gaussian distributions in *T* and *E* with dispe σ_T and σ_E

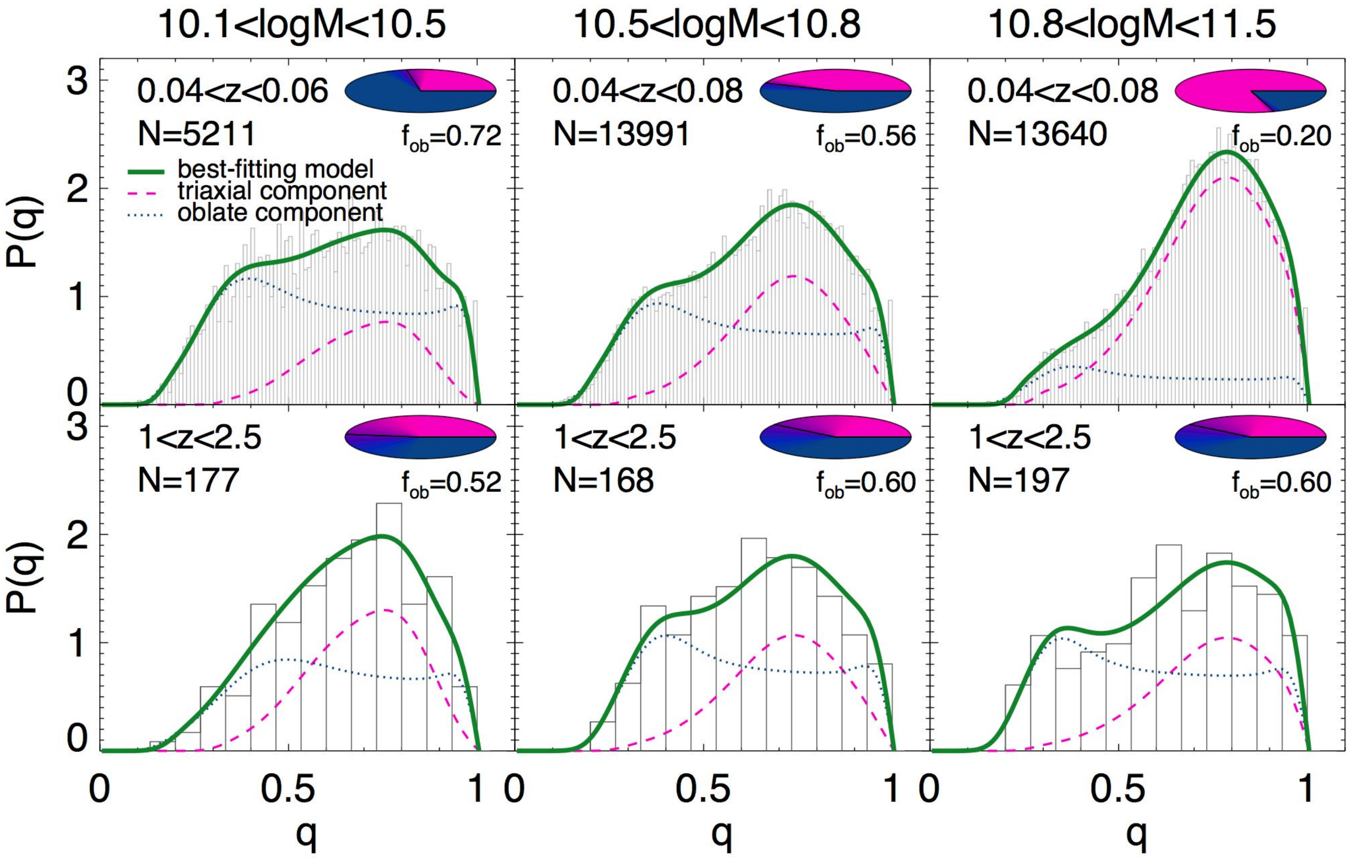
1. Numerically generate β and γ distributions
2. Assign random viewing angles (θ each element of distribution
3. Using the equation for *q*, generate the probability distribution for projected axial ratios



Finding the Best-fitting Triaxial Model

- Total likelihood is given by $L = \Sigma_{q_{data}} \log p(q_{data}|q_{model})$
- Create a grid spaced as (ΔT, $\Delta\sigma_T$, ΔE, $\Delta\sigma_E$)
- For low-redshift sample create a grid as (Δf_{obs}, ΔT, $\Delta\sigma_T$, ΔE, $\Delta\sigma_E$, Δb, $\Delta\sigma_b$)
    - The extra parameters are fraction of the oblate component, the intrinsic axis ratio of the oblate component and its standard deviation
- Test the goodness of fit with K-S and M-W tests

“Histograms show observed distributions of projected axis ratios for present-day early-type galaxies from SDSS (upper row) and at 1 < z < 2.5 from CANDELS (bottom row), each in three mass bins.”



Conclusions

- There is no single shape that can account for the observed axial ratio distribution
- A two-population model for intrinsic shapes is adequate to describe present-day and $z > 1$ early types.
- In the present-day, the oblate fraction strongly depends on the galaxy mass; this trend disappears at $z > 1$.
- Chang et al. attribute the lower incidences of disky structures at early cosmic time to the lack of settled star-forming progenitors, and the stripping of gas from disks in dense cosmic environments.
- Classical elliptical galaxies “[...] emerge over time through merging and accretion of satellites, at the expense [...] of pre-existing disks.”

References

1. Chang et al. (2013)
2. Fall and Frenk (1983)
3. Van der Wel (2014)