Dynamics of High Redshift Galaxies

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Lecture plan:

1. **Introduction. Galaxy kinematics at high redshift.**

2. **Dynamics of elliptical galaxies at high redshift and evolution of the Fundamental Plane.**

3. **Evolution of the black hole mass vs galaxy mass relation. Dynamics without kinematics.**

4. **Future developments in the study of the dynamics of high redshift galaxies.**

Overview of the lecture

- Measuring black hole masses at high-z and studying the evolution of the black hole vs galaxy mass relation

- Strong lensing diagnostics

- Masses of clusters of galaxies

- Stellar masses from near-IR photometry

- Correlation masses

- Dynamical information from imaging studies

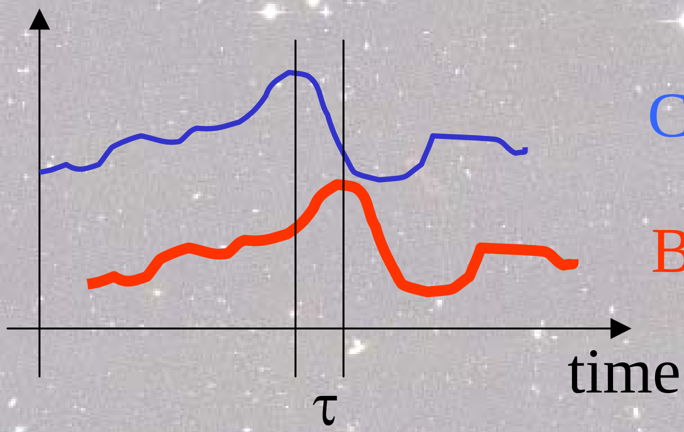
Measuring black hole masses at high-z

With few exceptions black hole masses in local quiescent galaxies have been measured starting from gaseous or stellar kinematics. These measurements require extreme angular resolution and, even with the Hubble Space Telescope, they are practical only for the nearest galaxies.

For black holes in active galaxies one can use other techniques such as *reverberation mapping* which relies on the variability of emission lines. One measures the time delay τ of a variable line with a given velocity width δv. The black hole mass is given by:

$$M = A\, c\tau\, \delta v^2 / G$$

Measuring black hole masses at high-z



Continuum luminosity

Broad line luminosity

Time delay

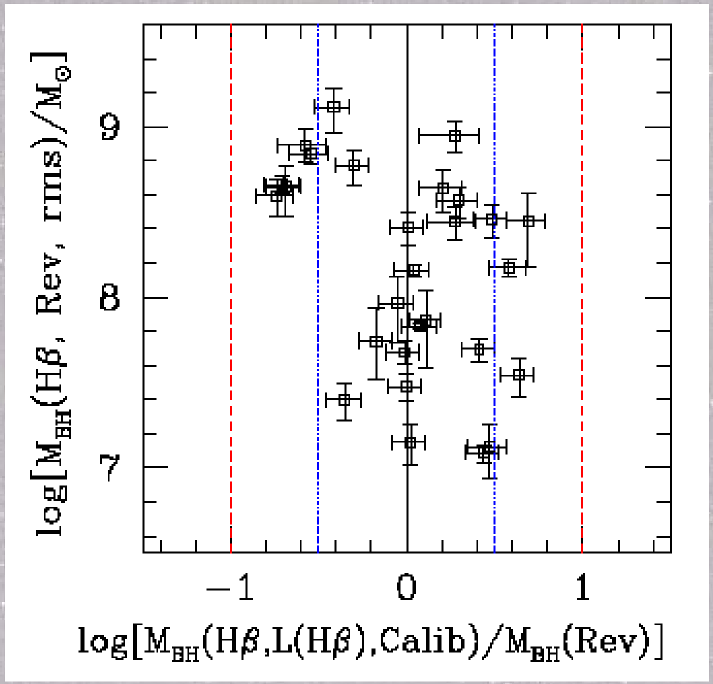
cτ is a lengthscale

The velocity width of the line provides a velocity scale.

$$M = A\, c\tau\, \delta v^2 / G$$

Measuring black hole masses at high-z

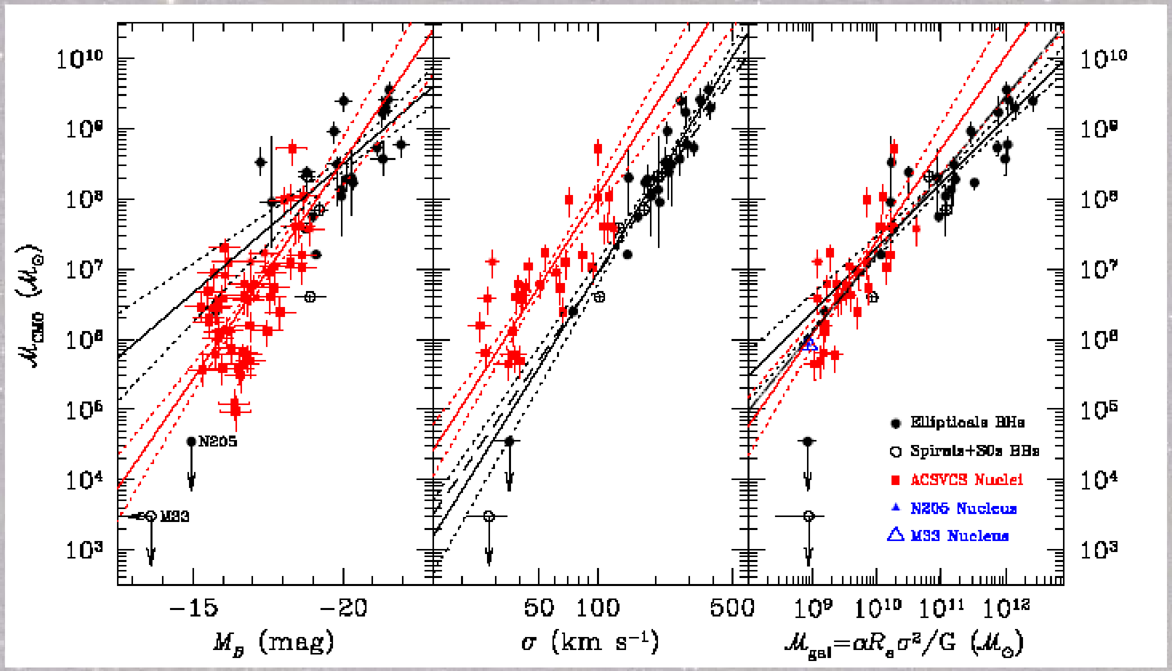
Luckily for us the availability of a large set of blackhole masses derived from reverberation mapping (e.g. Peterson et al. 2004) has allowed us to discover correlations between H mass and UV luminosity and line widths.



This is an example of the accuracy in measuring a black hole mass using a calibrated relation based on Hβ (Vestergaard 2006).

Measuring black hole masses at high-z

At low redshift there is a relation between black hole mass and mass or velocity dispersion of the spheroid hosting the black hole.

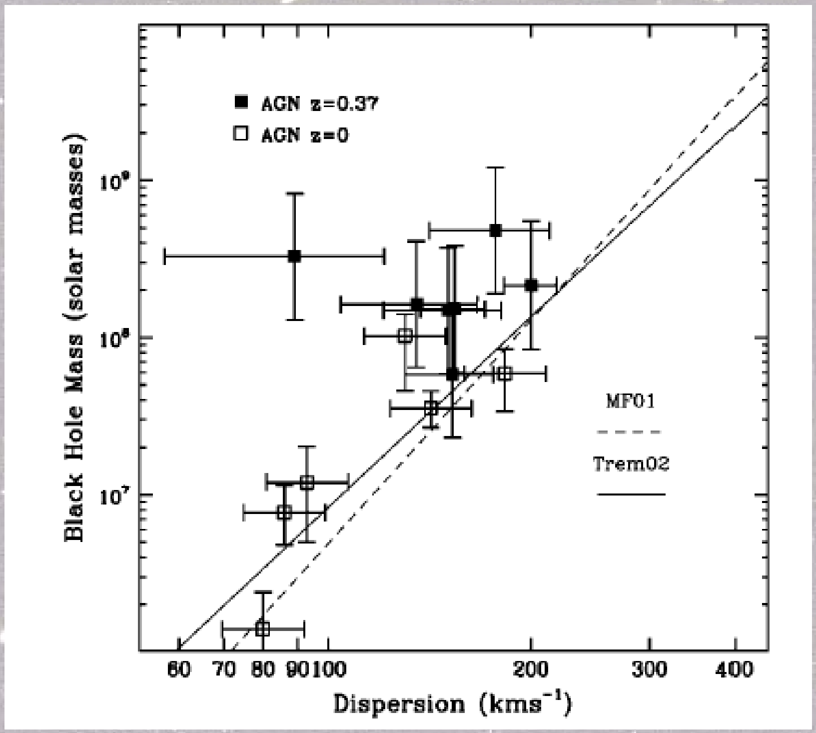


Correlation between black hole mass and host size as given by its absolute magnitude, velocity dispersion, or mass. (Vestergaard 2006).

How was this relation established? How did it evolve?

Measuring black hole masses at high-z

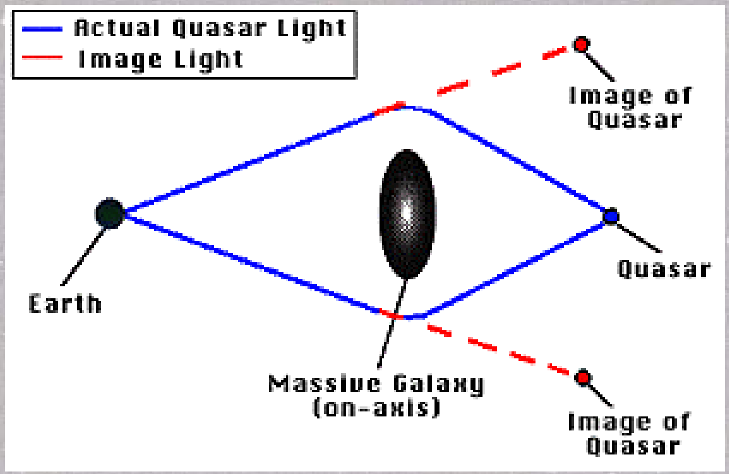
The evolution of the M_{BH}-σ relation has been studied up to redshift 0.37 by Treu et al. 2004, 65, L97. This is a first result that could be pushed to higher z.

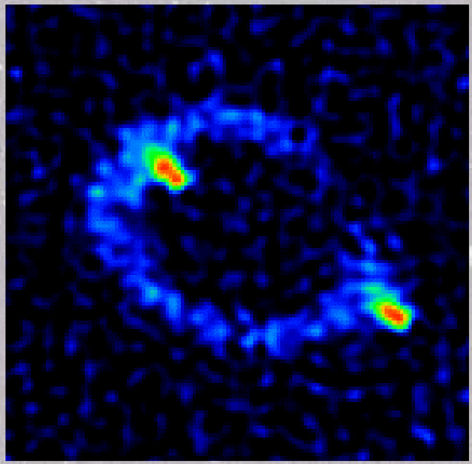


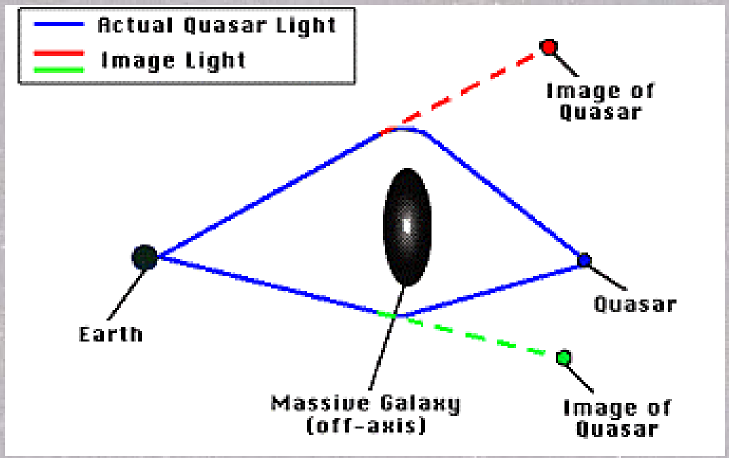
Preliminary result suggesting that Seyfert galaxies gained factor 2 in velocity dispersion.

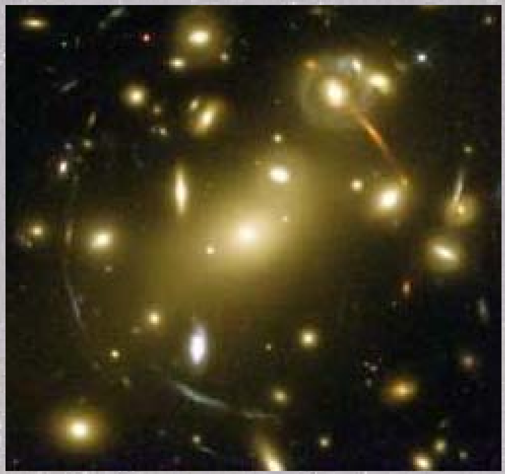
Strong lensing diagnostics

Lensing is called strong when it produces rings or arc-like images





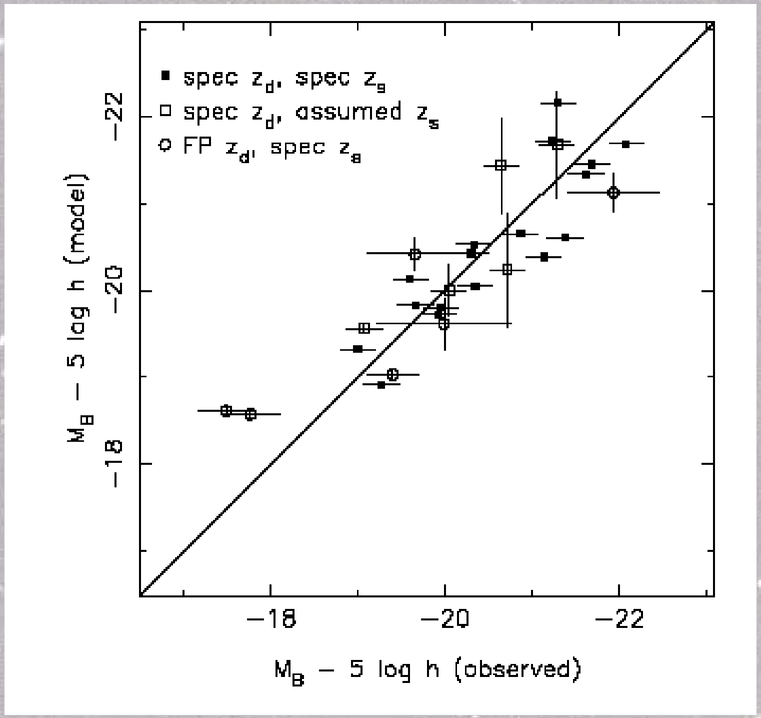




Note: lensing conserves surface brightness. Lensed objects are brighter because they appear larger in area.

Strong lensing diagnostics

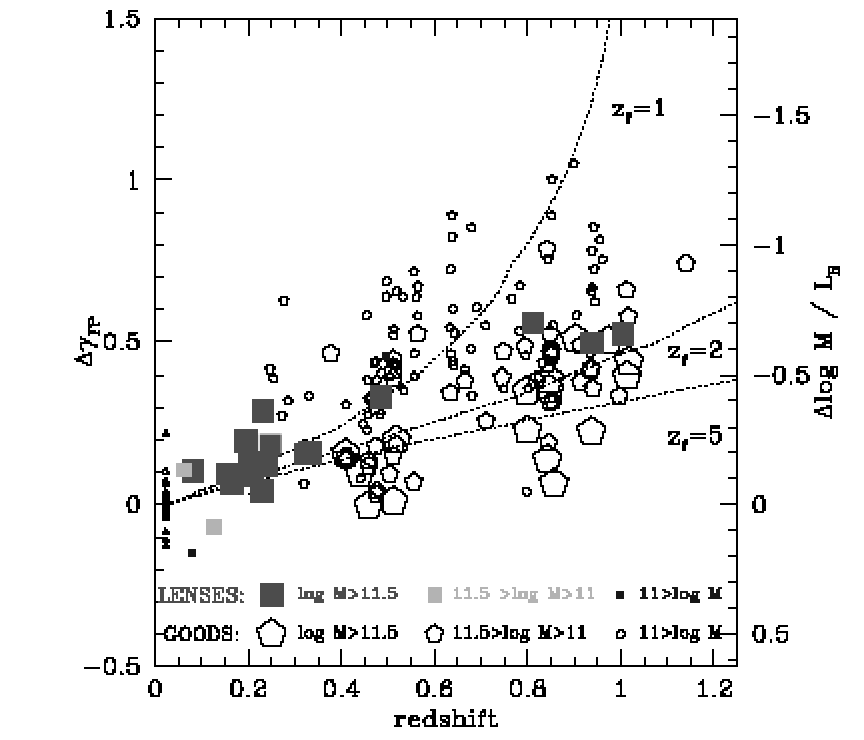
Gravitational lensing (strong lenses) can be used to derive an analog of the fundamental plane relying simply on imaging data (Rusin, Kochanek et al. 2002).



Observed absolute magnitude vs "prediction" from the Faber Jackson relation and lensing.

Strong lensing diagnostics

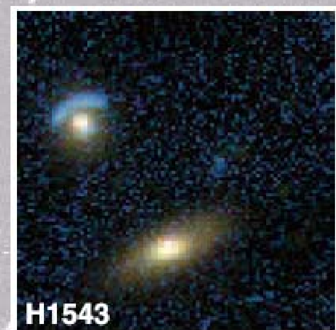
As we saw previously this measurement can be used for objects with a tranditional FP measurement in order to check for structural evolution.

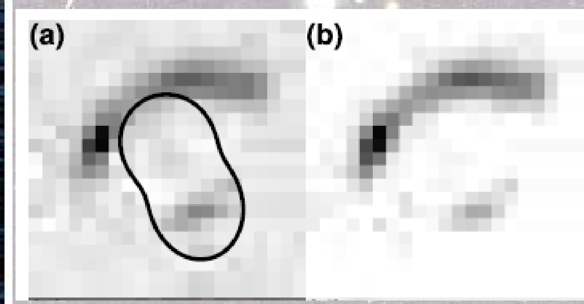


Evolution of the FP zero-point adding lenses.

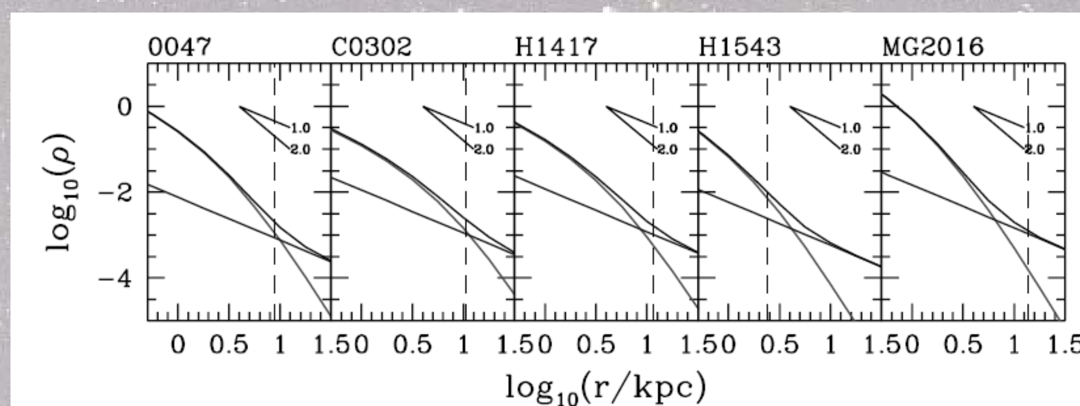
Strong lensing diagnostics

Lensing can also be used to begin constraining the properties of the dark halo. This is done from a combined model including lensing and kinematics. So far only 5 lenses have been studied in detail.





1. Constant M/L models are excluded
2. Average total mass slope is –1.75
3. Average total dark matter slope is –1.3
4. M/L evolution best explained by stellar evolution



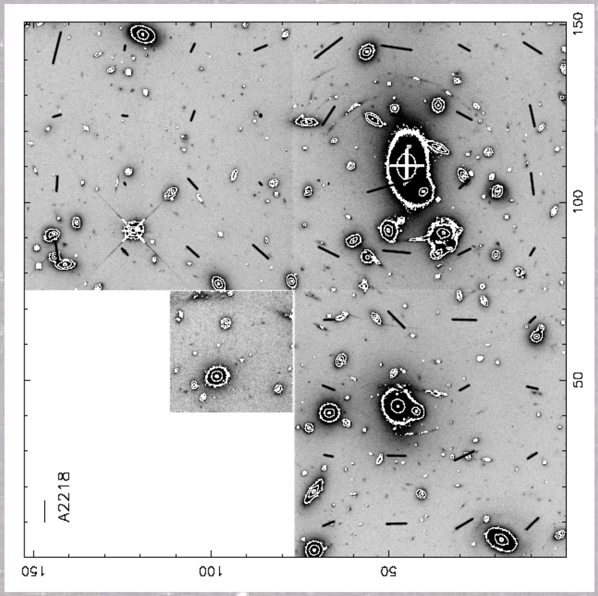
Treu & Koopmans 2004, ApJ, 611, 739

Clusters of galaxies

Multiple mass indicators are available for clusters of galaxies:

• X-ray emitting gas can be used to derive information on the mass of galaxies and clusters. Detecting clusters in X-rays becomes very hard at z=1.2 (but some clusters have been discovered with this method).
• Weak lensing can give us a mass distribution (both visible and dark)
• Velocity dispersions can be obtained by computing the dispersion of the radial velocities of cluster members.

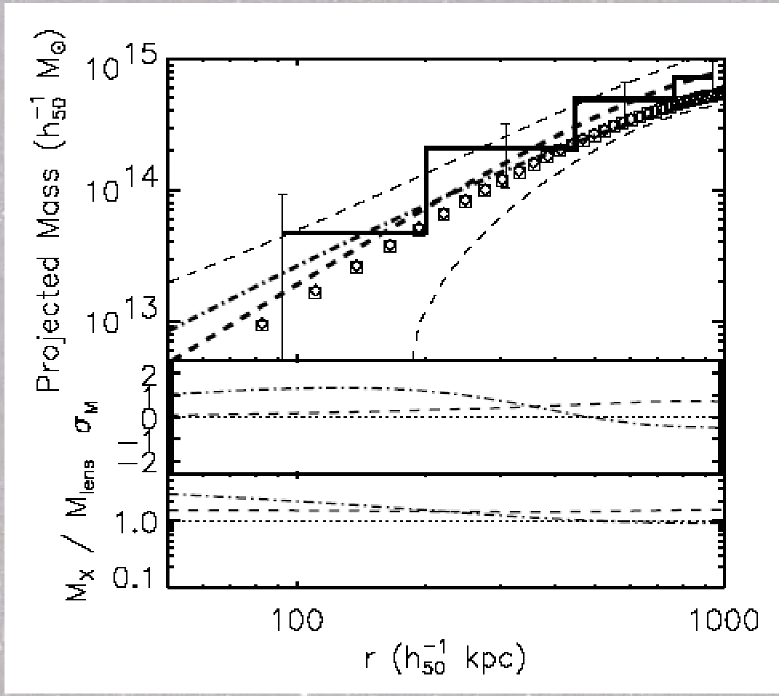
Smail et al. 1987, ApJ, 479,70 found that weak lensing mass and velocity dispersion often disagree (by 50%). This may be due to structures or membership errors in deriving the velocity dispersion.



Clusters of galaxies

Gravitational vs X-ray mass comparison can be done in great detail and occasionally shows disagreement which might be due to either a prolate shape of the gas distribution or to the fact that the cluster hot gas is not in equilibrium.

Ettori & Lombardi 2002, AA, 398, L5 do this comparison for MS1008.1-1224 at z=0.3. They find good agreement between the two mass profiles. In the figure the X-ray profile is given by the solid steps while the symbols give the weak-lensing mass.

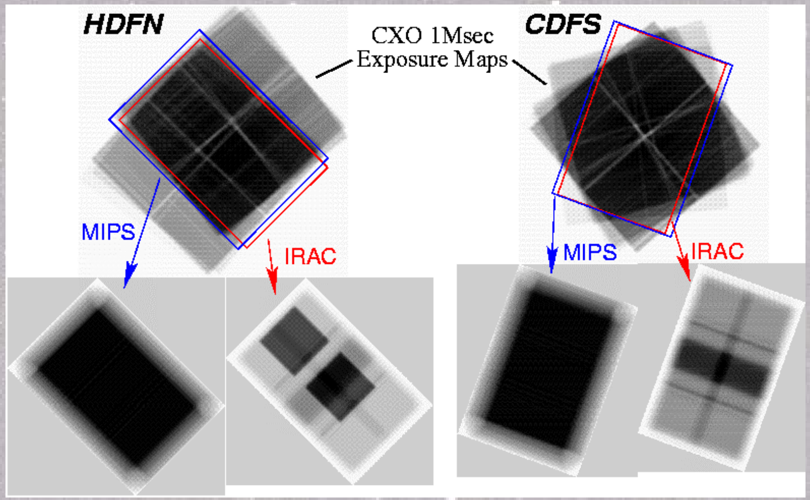


Stellar masses from IR photometry

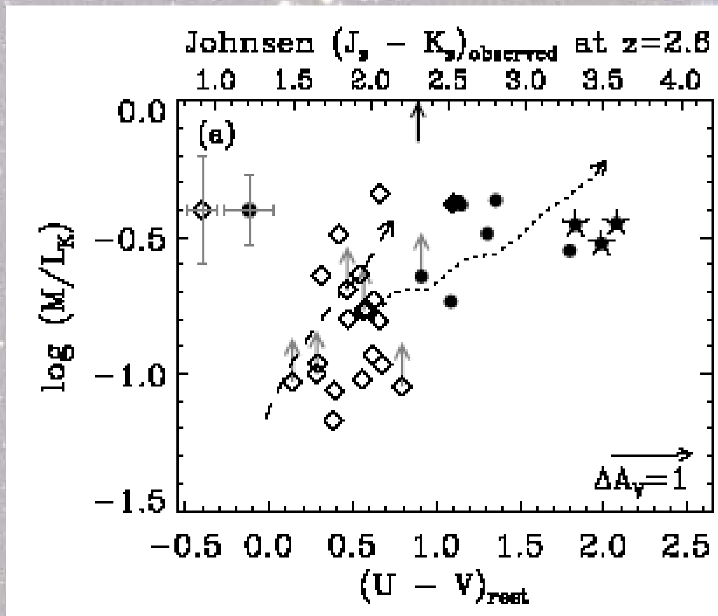
The M/L of stellar populations in the H or K bands is relatively insensitive to changes in stellar population properties like age, metallicity, star formation history. This allow us to derive photometrically stellar masses. The accuracy is about a factor of 3.

The availability of the Spitzer Space Telescope with good sensitivity to 8μm allows us to derive stellar masses for galaxies up to z=4.

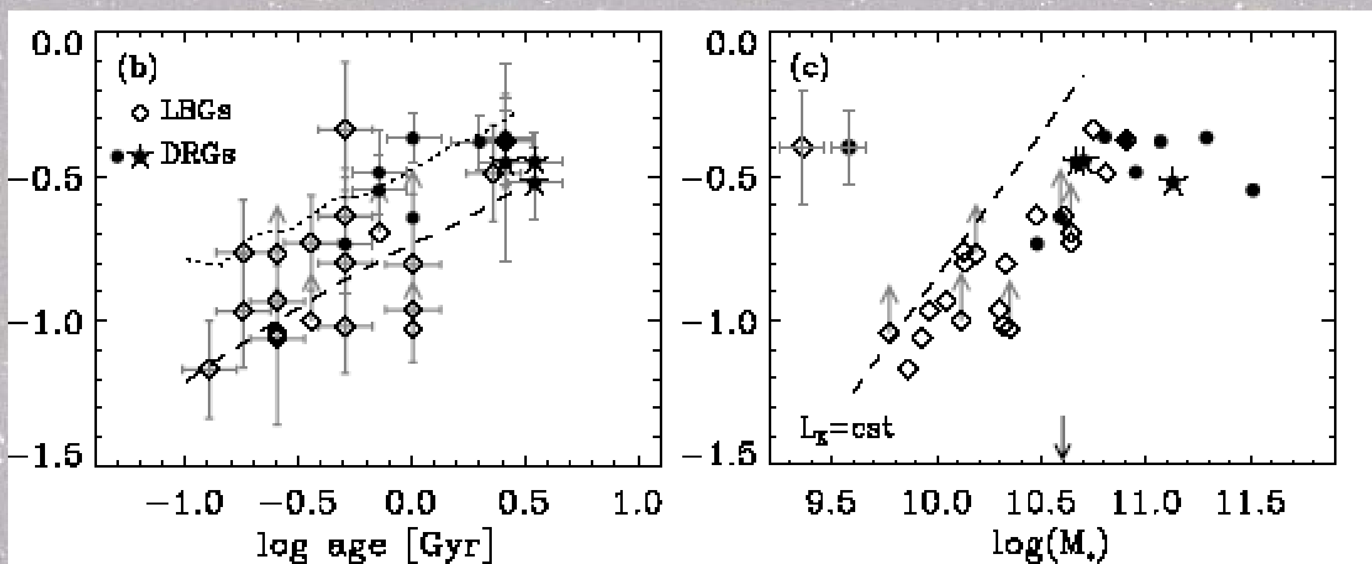
Within the GOODS survey the stellar mass is derived from a complete SED fit at wavelengths ranging from 0.36 to 8 μm.



Stellar masses from IR photometry

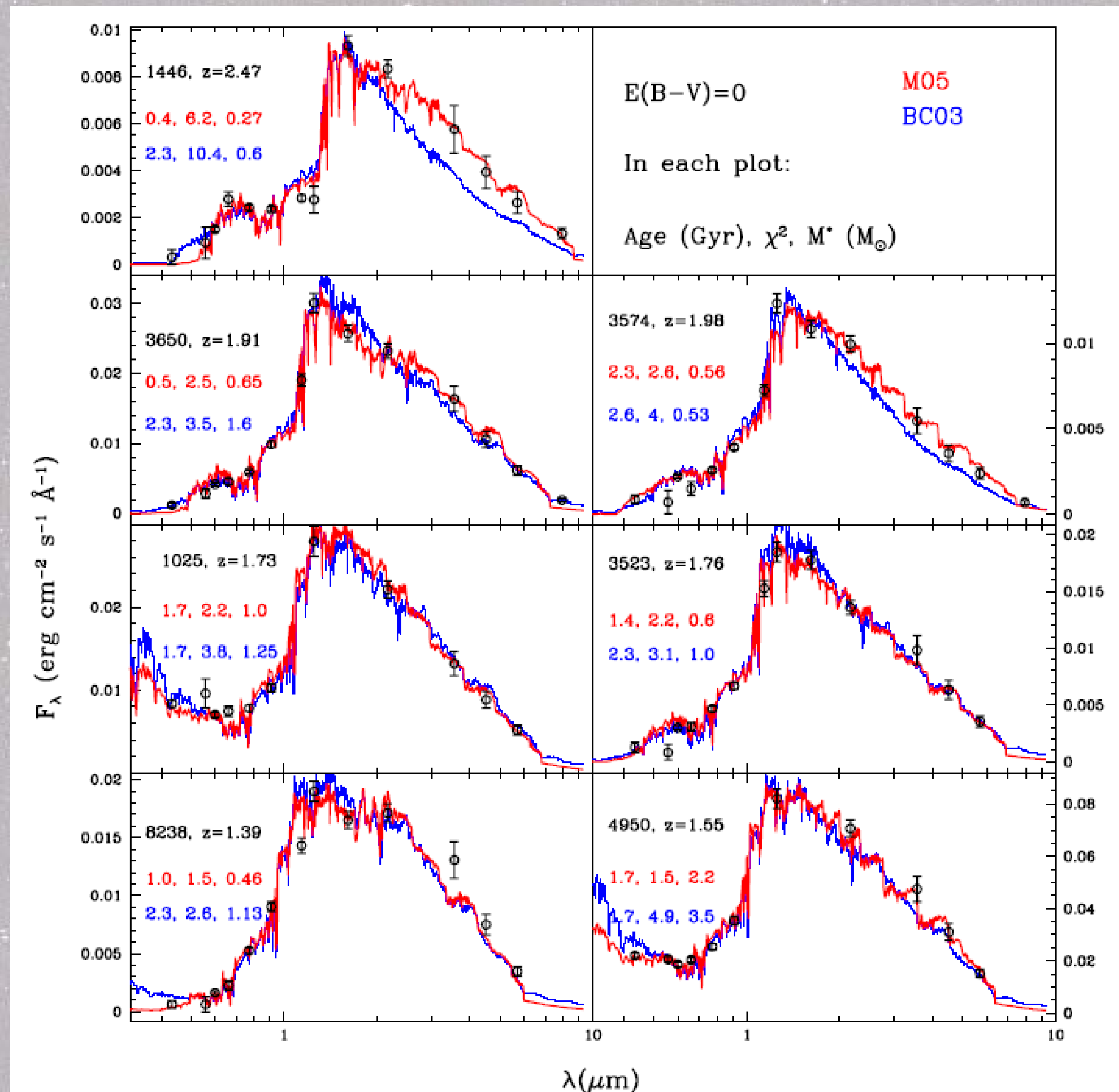


The availability of stellar masses allows us to correlate M/L with properties like age and stellar mass. Distant red galaxies (fixed symbols), Lyman break galaxies (diamonds). Labbe' et al. 2005.



Stellar masses from IR photometry

Models by Maraston (2005) including a different treatment of the AGB predict roughly similar stellar masses to those derived from Bruzual and Charlot models (60 per cent lower), but stellar ages up to a factor 6 younger.



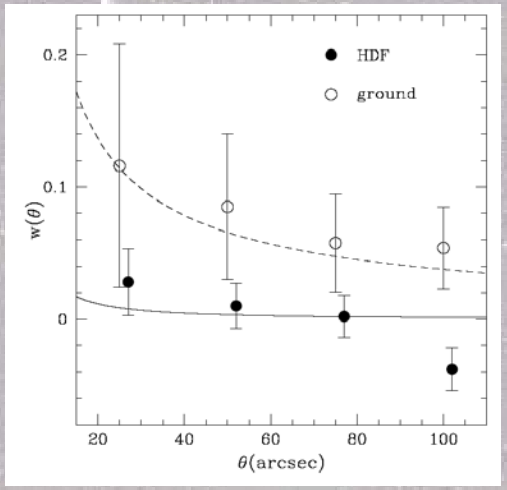
Correlation masses

CDM theory tells us how the two-point correlation function at various mass scales varies with redshift. The correlation functions gives us the probability of finding an object at distance r from another:

$$p(r) = n\,(1+\xi(r))$$

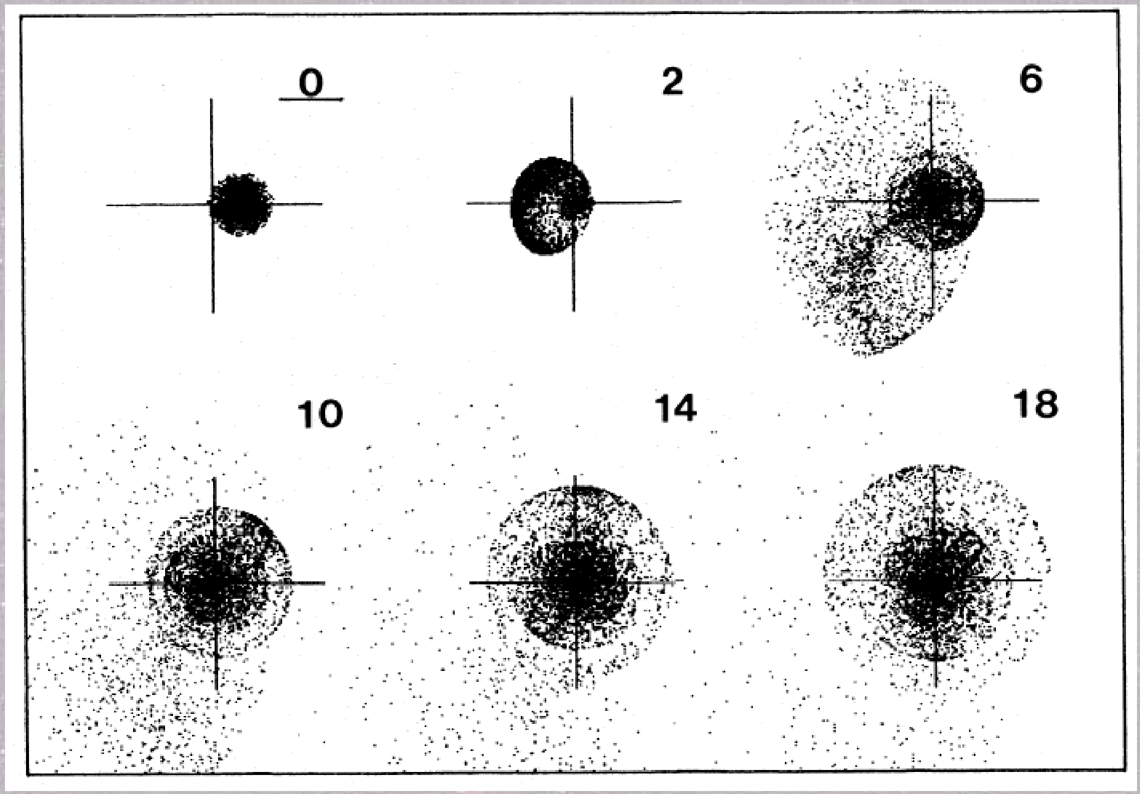
By measuring the correlation function of a class of objects we can determine the mass scale of their dark halos assuming that CDM applies.

Till recently data sets where not large enough to reach firm conclusions (Giavalisco et al 2000, Porciani & Giavalisco 2001). This may change with GOODS and COSMOS



Dynamical information from imaging

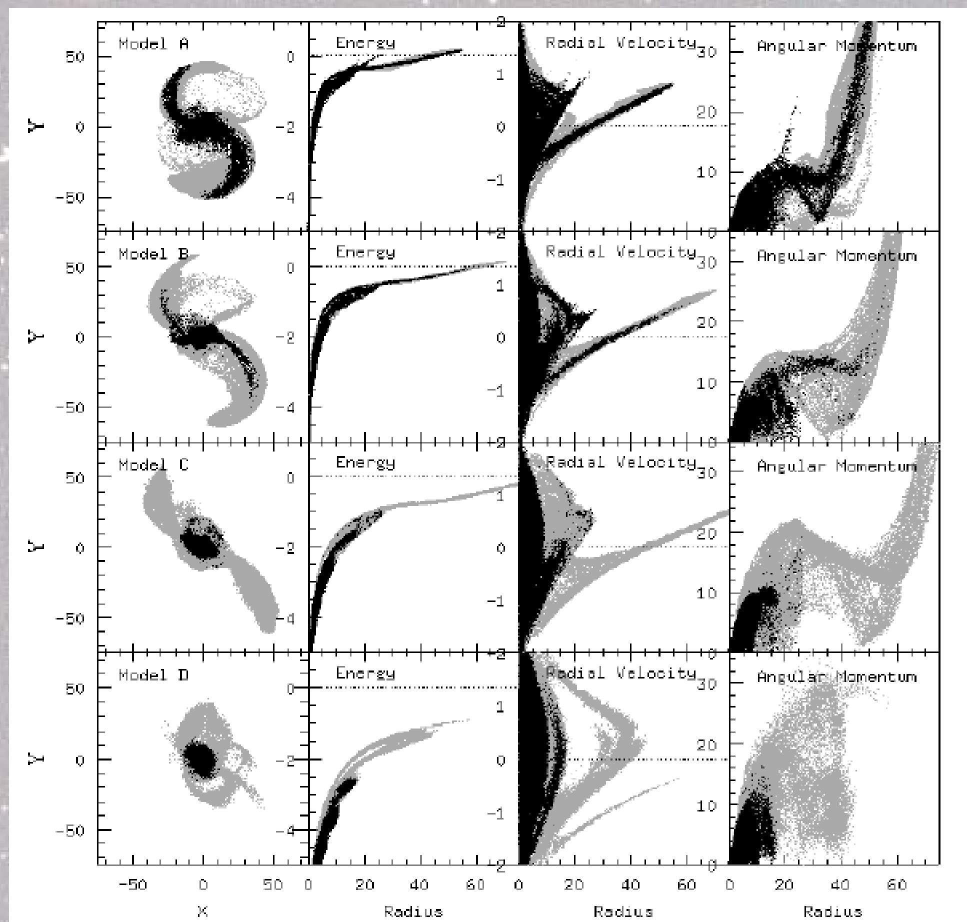
Deep imaging can provide us with details about faint structures around galaxies like shells, tidal tails etc. This structures can be modeled by using numerical simulations. This type of study can lead to constraints on the structural or dynamical properties of the objects.



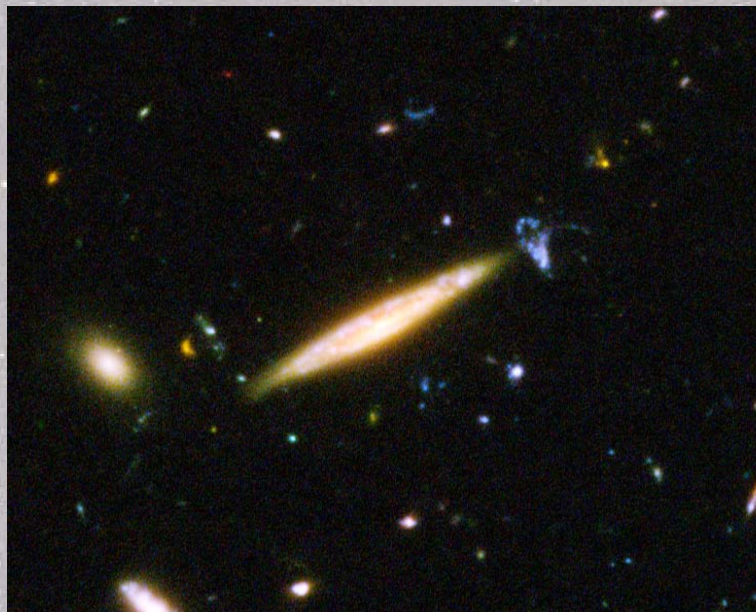
Quinn (1984) was the first to suggest that shells could be used to derive information on dark halos, but it’s harder than it looks…

Dynamical information from imaging

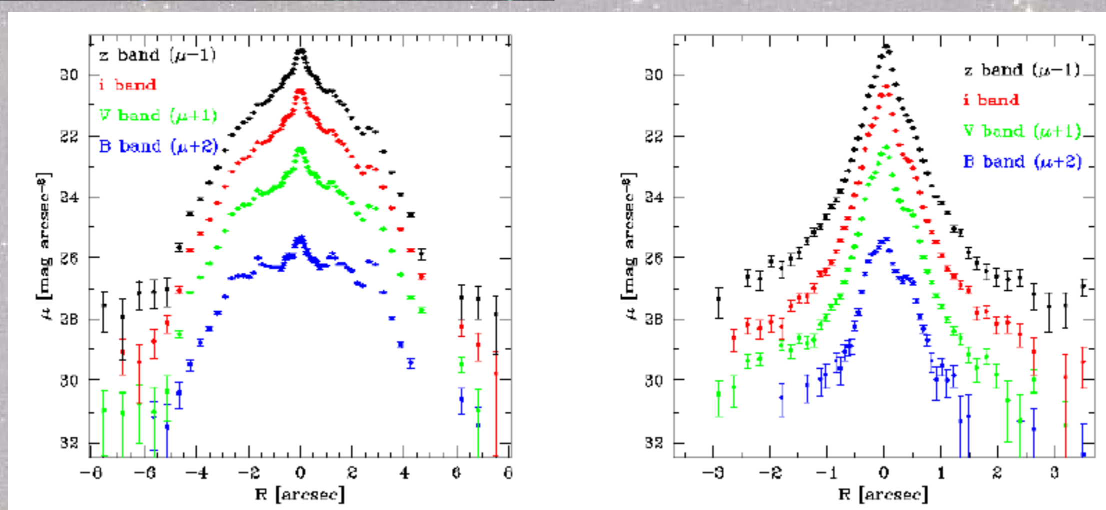
Mihos et al. (1998, ApJ, 494, 183) used tidal tails to contrain the size of dark halos.



Dynamical information from imaging



Zibetti and Ferguson (2004): the UDF is deep enough to study faint halo structure (μ~29) in galaxies at z=0.3 with comparable sensitivity to what we have on M31, a thousand time closer.



Summary

The details are not so important but I have on recommendation:

Focus on the astrophysical problem rather than on a technique and use all techniques that are relevant to solve the problem!