Dynamics of High Redshift Galaxies

M. Stiavelli, STScI Baltimore

Main goal: understanding how galaxies form and evolve

- Evolution of the global galaxy correlation laws

  Dynamics is a tool to measure :

  - Masses
  - Structural properties

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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.**

General Introduction

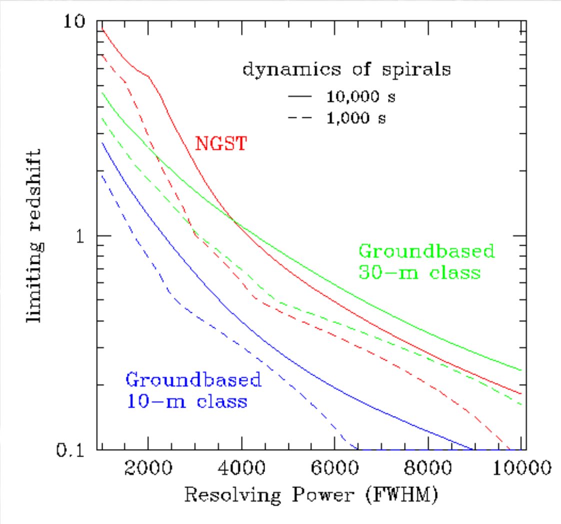
- Aim : Discuss some modern problems in High-z Dynamics
  Present a few well-developed techniques

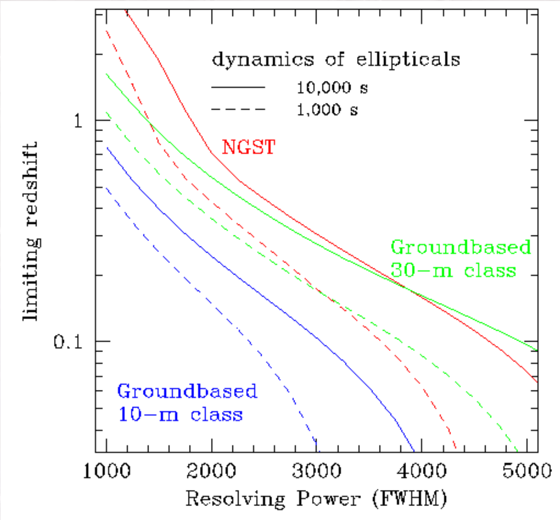
- Cautionary notes:
  - *Angular resolution and sensitivity are serious limitations for these studies.*
  - *Observing techniques are well matched to theoretical understanding (unlike the situation in the local Universe where theory is lagging behind).*

- Use the right instrument for any observation

Space-based and ground-based telescopes

- Space telescopes have very stable observing conditions and very low natural backgrounds: they are hard to beat for deep imaging.
- Ground based telescopes have large collecting area and are easier to keep updated with modern instrumentation. They are especially suited for high spectral resolution applications.





Comparison between NGST (now JWST) and ground based telescopes. The latter are superior for R>4000.

Adaptive Optics

- Great promise but slow progress.
- The advantage of stability and low background of space telescopes remain even if adaptive optics works.
- Present systems are very limited: the field of view around the guide star is very small if one requires a Strehl ratio no lower than 50 per cent (in JHK).

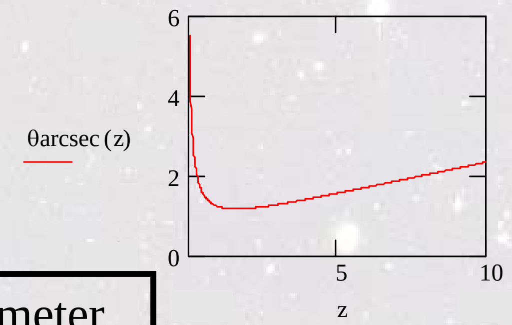
V	on-axis SR (0.8″)	SR at 30″ (0.8″)	on-axis SR (1.2″)	SR at 30″ (1.2″)
10.0	47	9	32	1.5
11.5	44	9	12	1.4
13.0	26	7	7	1.3
14.5	17	5	5	1.0
16.0	5	3	1	0.7

HST before spherical aberration correction had a Strehl of 15%. Present HST > 85%.

- Integral Field Units on ground based telescopes with adaptive optics will be very useful.

Length and age

Some useful quantities as a function of redshift in the concordance model (Λ = 0.7, H_0 = 70 km s^{-1} Mpc^{-1}):

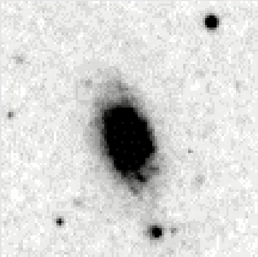


Redshift	Universe Age (Gyrs)	Apparent diameter of 10 physical kpc
Present epoch	13.7	-
0.5	**8.7**	**1.6”**
1	**6**	**1.2”**
2	3.4	1.2”
3	2.2	1.3”
5	1.2	1.6”
6	1	1.7”
15	0.3	3.1”

Morphological type

Caution in adopting a characterization: NGC 3259 - SAB(rs)bc:

DSS

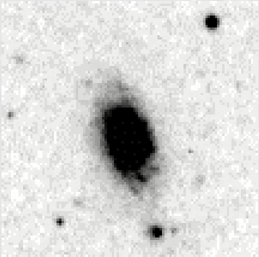


The RC3 classification is done on Schmidt plates like those used for the Digital Sky Survey.
It’s clear how NGC 3259 could be classified as intermediate between barred and non-barred.

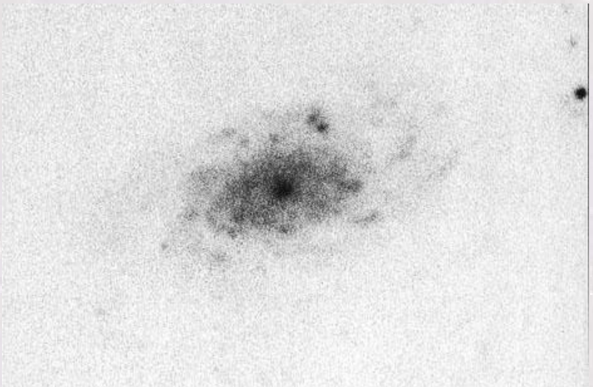
Morphological type

Caution in adopting a characterization: NGC 3259 - SAB(rs)bc:

DSS



5m Palomar

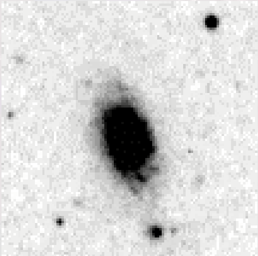


The image at the 5m doesn't show significant evidence for a bar but confirms the presence of a small bulge compatible with the "bc" classification.

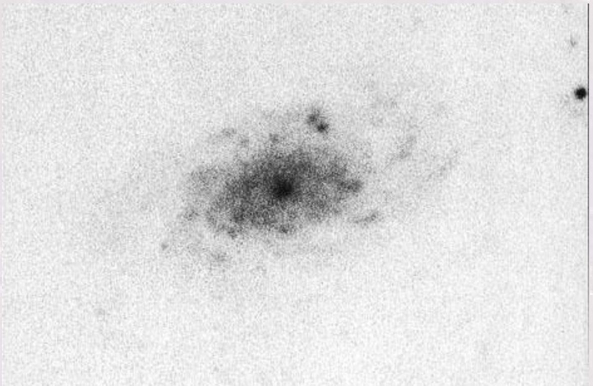
Morphological type

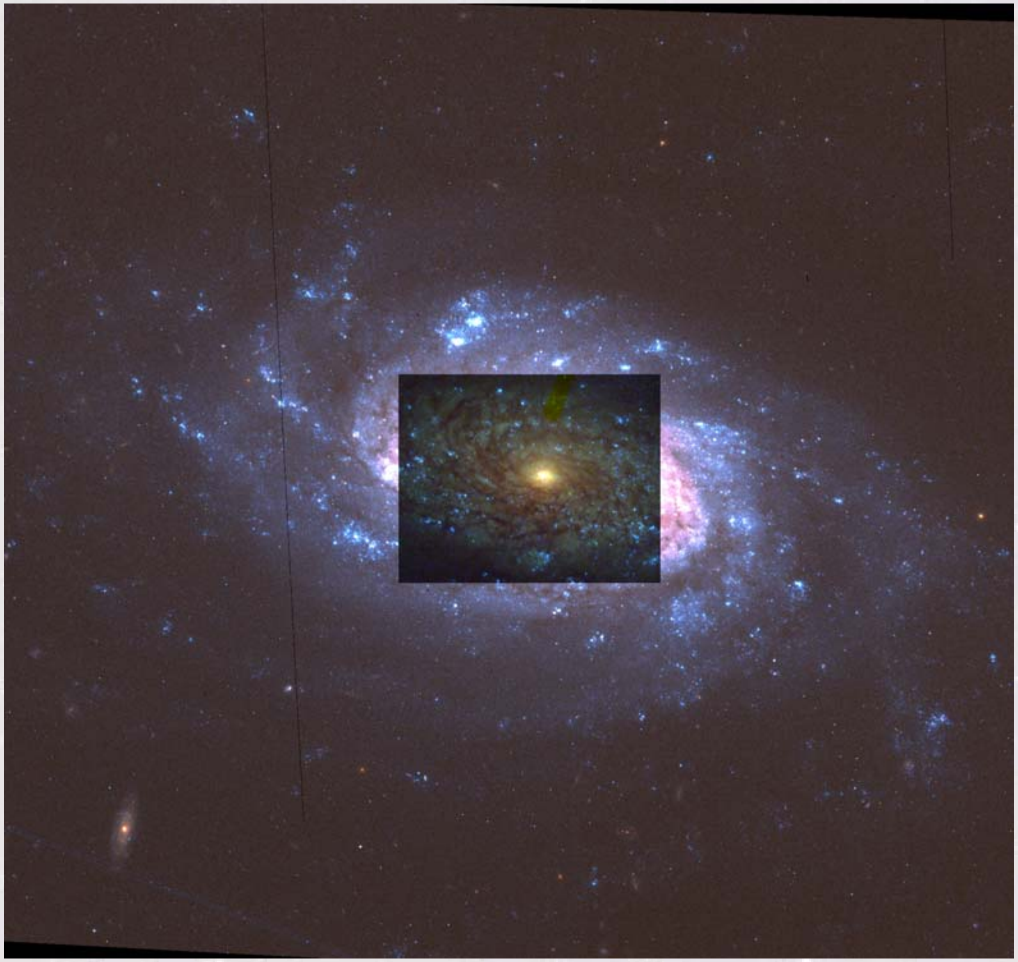
Caution in adopting a characterization: NGC 3259 - SAB(rs)bc:

DSS



5m Palomar

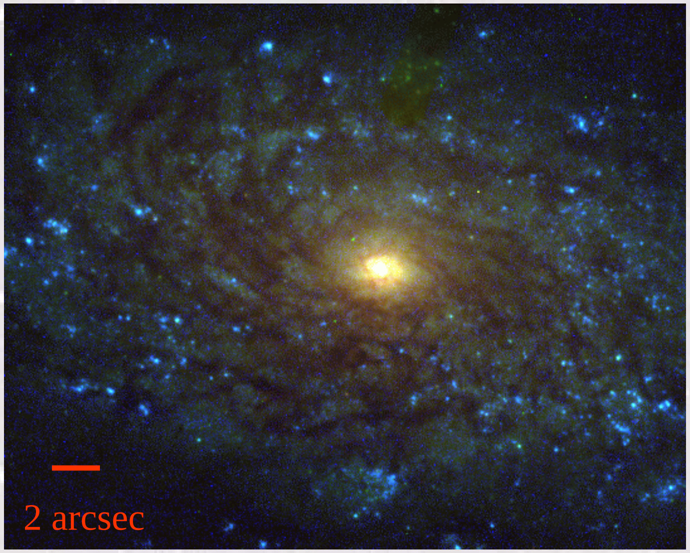




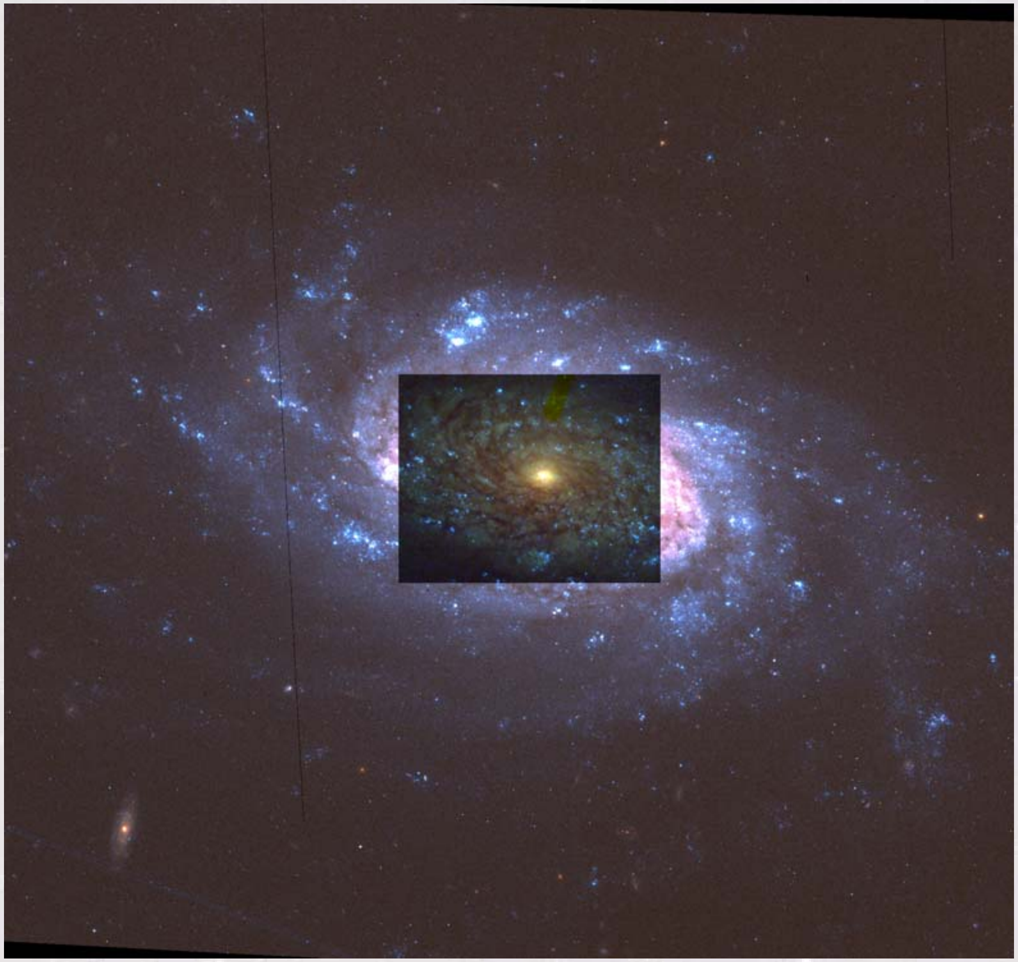
HST with ACS

Morphological type

Caution in adopting a characterization: NGC 3259 - SAB(rs)bc:

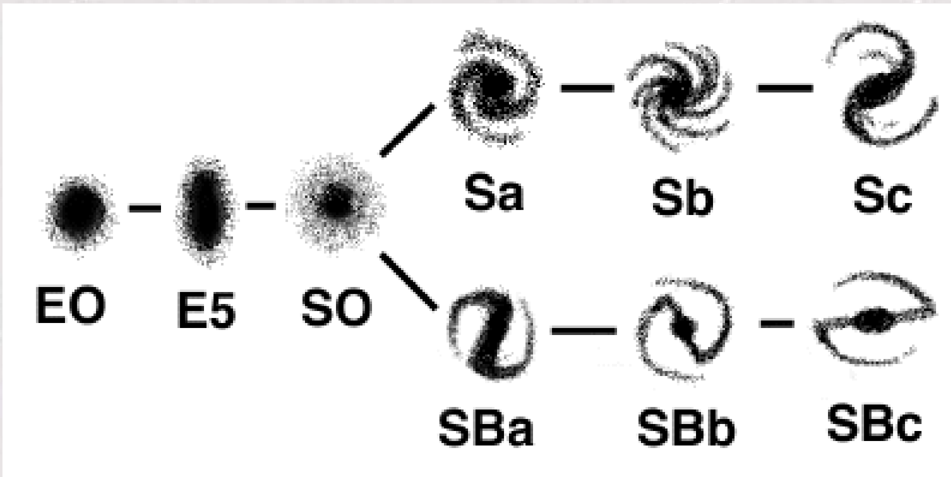


The HST image shows that the bulge does not exist and that the galaxy as a disk reaching down to the nucleus and a compact nuclear source.



HST with ACS

Morphological types



Hubble diagram

Simplified classification

At high redshift it is progressively harder to see sufficient details for a detailed classification and one adopts a simplified classification. For instance:

- Z < 1 : ellipticals, lenticulars, non-barred spirals, barred spirals
- Z > 1 : early type (ellipticals+lenticulars), disks (spirals w or w/o bars)

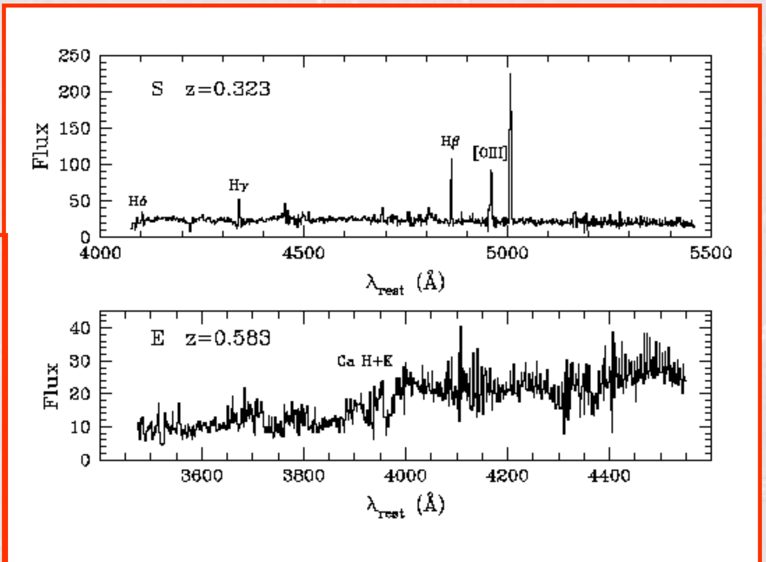
Kinematics vs Dynamics

Kinematics : studies the motions of gas and stars without regard to the forces driving them. → Spectroscopic measurements

Gas : emission lines

Stars : absorption lines

Example: two VLT+FORS1 spectra (1hr long) of galaxies with similar continuum magnitudes. Emission lines are much easier to use than absorption lines.



Dynamics : studies the effects of forces. By connectings forces with motions it allows us to measure masses or to characterize the equilibrium states of galaxies.

Kinematics vs Dynamics

We can imagine two types of problems in dynamics:

1. Mass measurements. One needs a lengthscale "r" and a velocity scale "v" in order to measure the mass $M = r\, v^2 / G$.

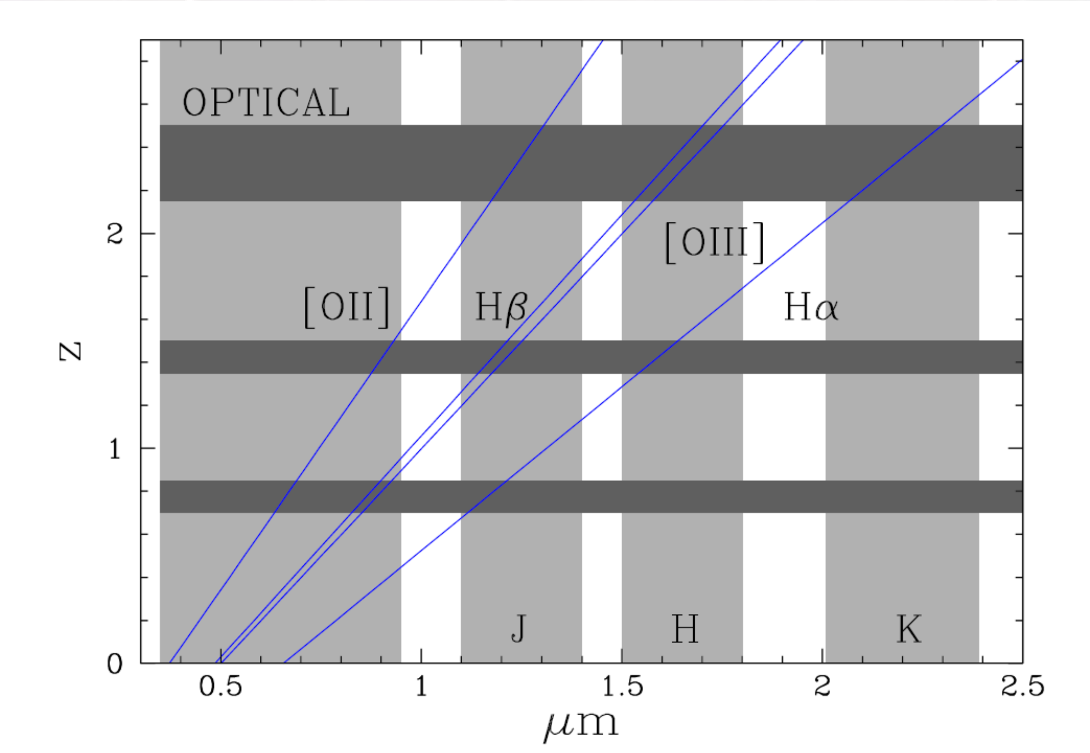
   This includes galaxy masses, central black holes, masses of groups or clusters of galaxies.

2. Structural measurements. One combines several measurements to derive information on the dynamical state of galaxies such as origin of flattening, velocity tensor anisotropy, presence of radial orbits, etc.

   These are the hardest to do at high redshift because of the extreme angular resolution and sensitivity requirements.

Kinematics : rotation curve (or profile amplitude)

I'll consider only optical emission lines because HI profiles or stellar absorption lines are very hard to measure at high redshift.

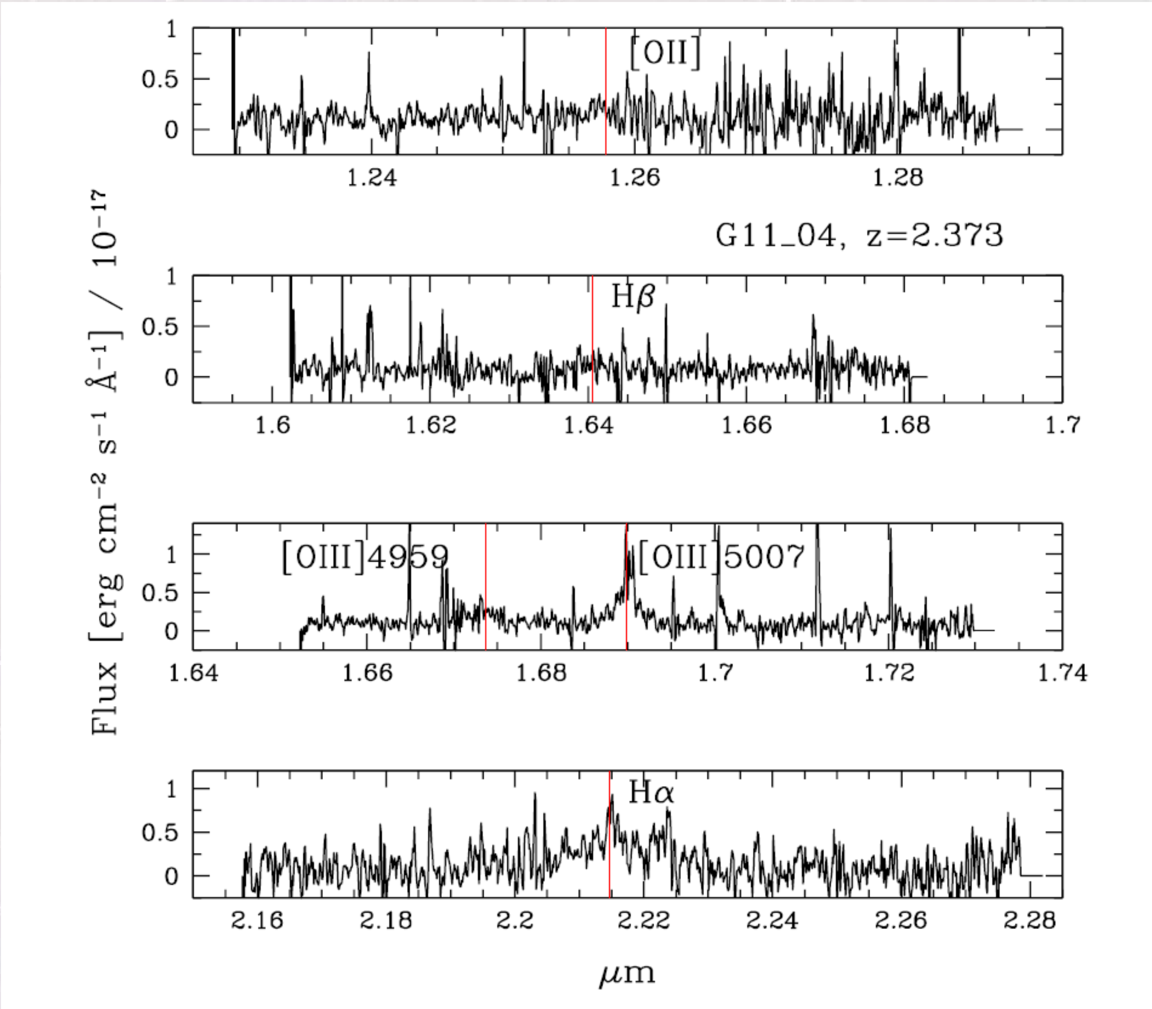


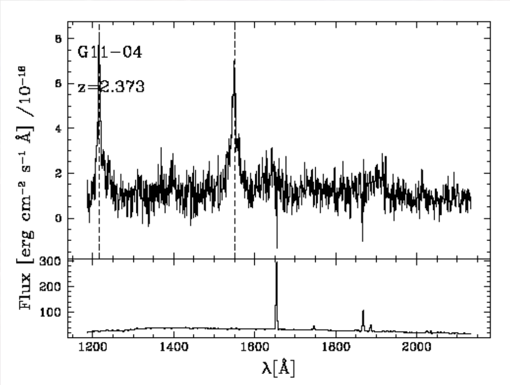
Only discrete redshifts where this is possible in the near-IR

(Scarlata 2004)

Kinematics : rotation curve (or profile amplitude)

Near-IR measurements are difficult (compared to optical).





VLT+FORS1 2400s

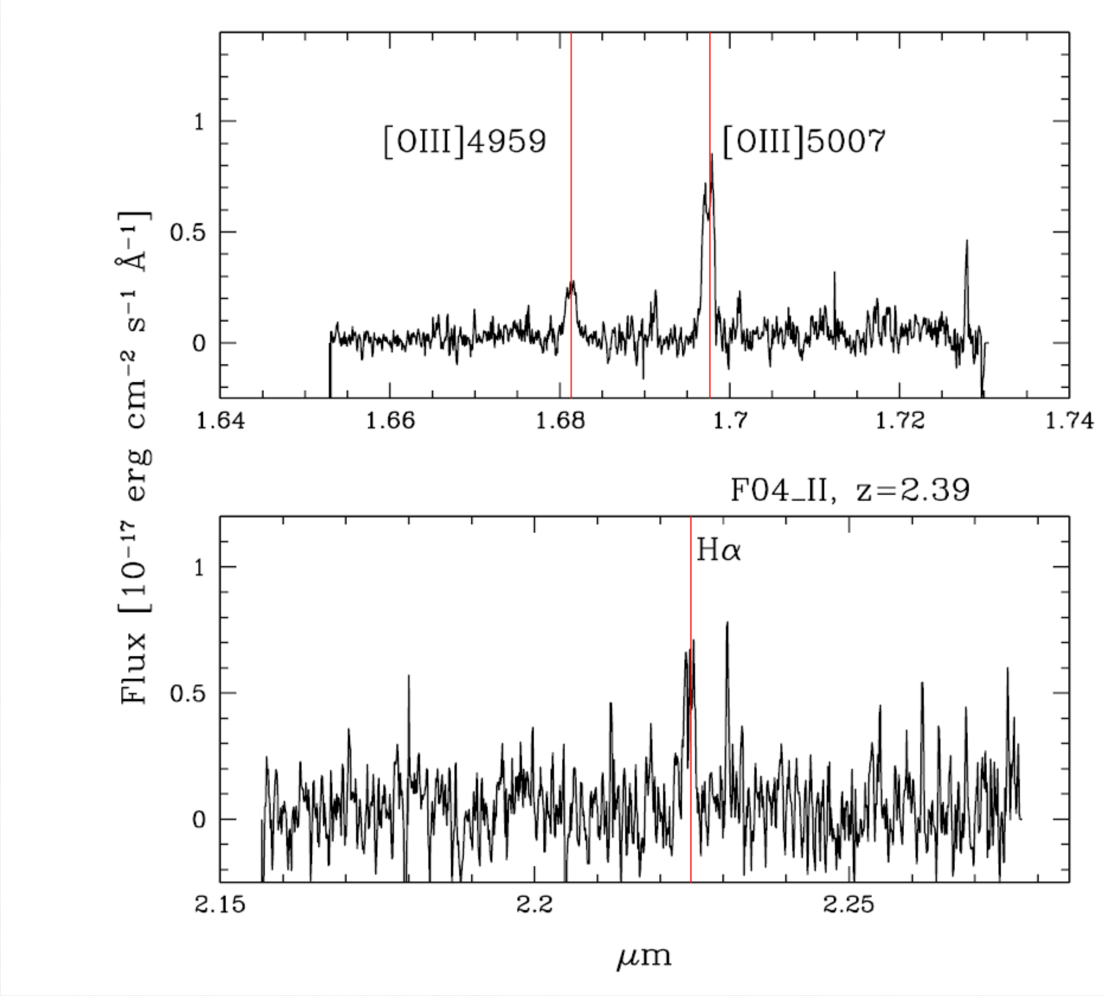
AGN!

Each spectrum required 3000s with the VLT+ISAAC under subarcsecond seeing.

(Scarlata 2004)

Kinematics : rotation curve (or profile amplitude)

In some cases one can measure a velocity profile…



(Scarlata 2004)

Kinematics : rotation curve (or profile amplitude)

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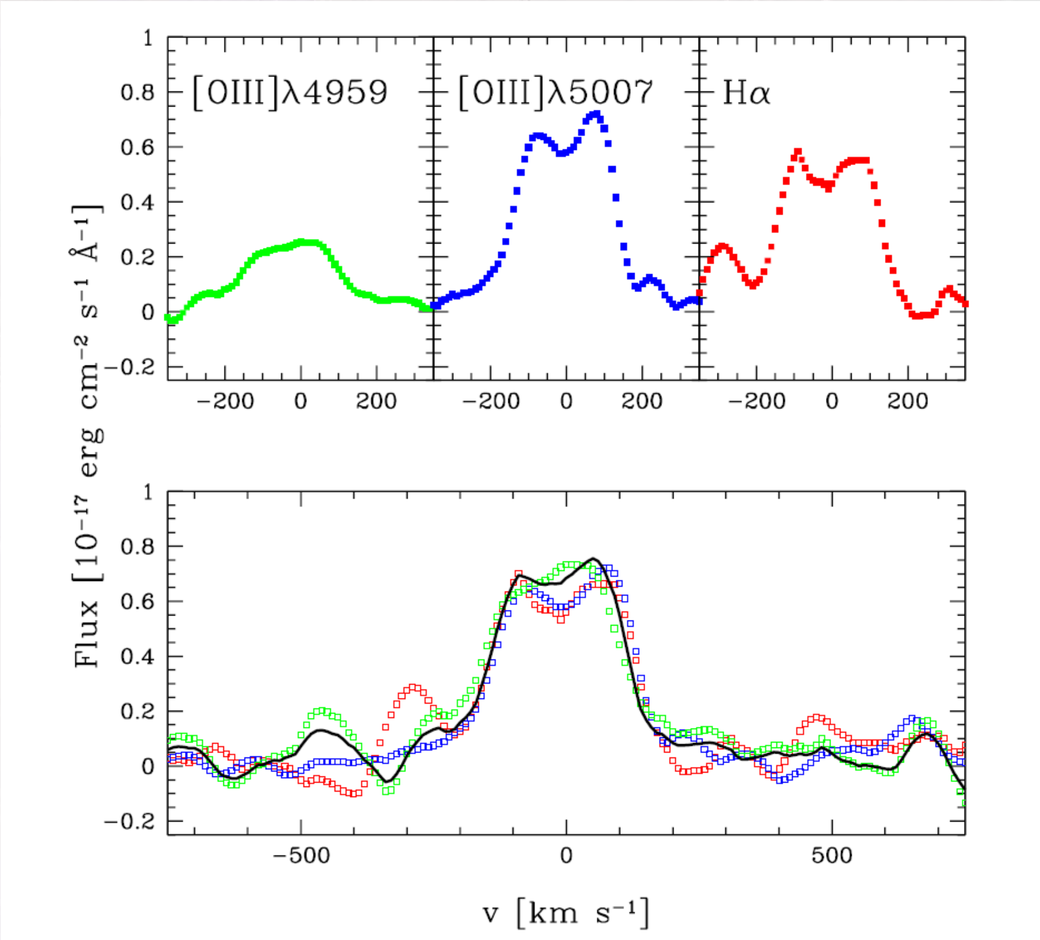


Emission–Line Fluxes	Fit
[O III]λ4959:	
$F(\times 10^{-17}\,\mathrm{erg\,cm^{-2}\,s^{-1}})$	0.37 ± 0.1
EW_{RF} (Å)	27.9
W_{20} (km s^{-1})	380±35
[O III]λ5007:	
$F(\times 10^{-17}\,\mathrm{erg\,cm^{-2}\,s^{-1}})$	1.16 ± 0.06
EW_{RF} (Å)	78.8
W_{20} (km s^{-1})	340±15
Hα:	
$F(\times 10^{-16}\,\mathrm{erg\,cm^{-2}\,s^{-1}})$	1.01 ± 0.06
EW_{RF} (Å)	65
W_{20} (km s^{-1})	350±20
$f_K(\times 10^{-17}\,\mathrm{erg\,cm^{-2}\,s^{-1}\,Å^{-1}})$	0.047 ± 0.04
$f_H(\times 10^{-17}\,\mathrm{erg\,cm^{-2}\,s^{-1}\,Å^{-1}})$	0.045 ± 0.04

(Scarlata 2004)

Kinematics : rotation curve (or profile amplitude)

The difficulties of this type of measurement explain why rotation velocities are generally not measured beyond redshift 1, i.e. they are measured mostly when some emission lines remain in the visible spectrum. True velocity fields are extremely hard to obtain.

Kinematics : velocity dispersion

- If measuring rotation curves at z>1 is hard, measuring velocity dispersions is harder.
- Stellar velocity dispersions rely on multiple or complex lines. In order to measure velocity dispersions accurately it's necessary to compare observed lines in galaxies with those in stellar templates with similar age and metallicity.
- If $L(\lambda)$ is the template line profile, $O(\lambda)$ the observed profile, and $P(v)$ the velocity profile :

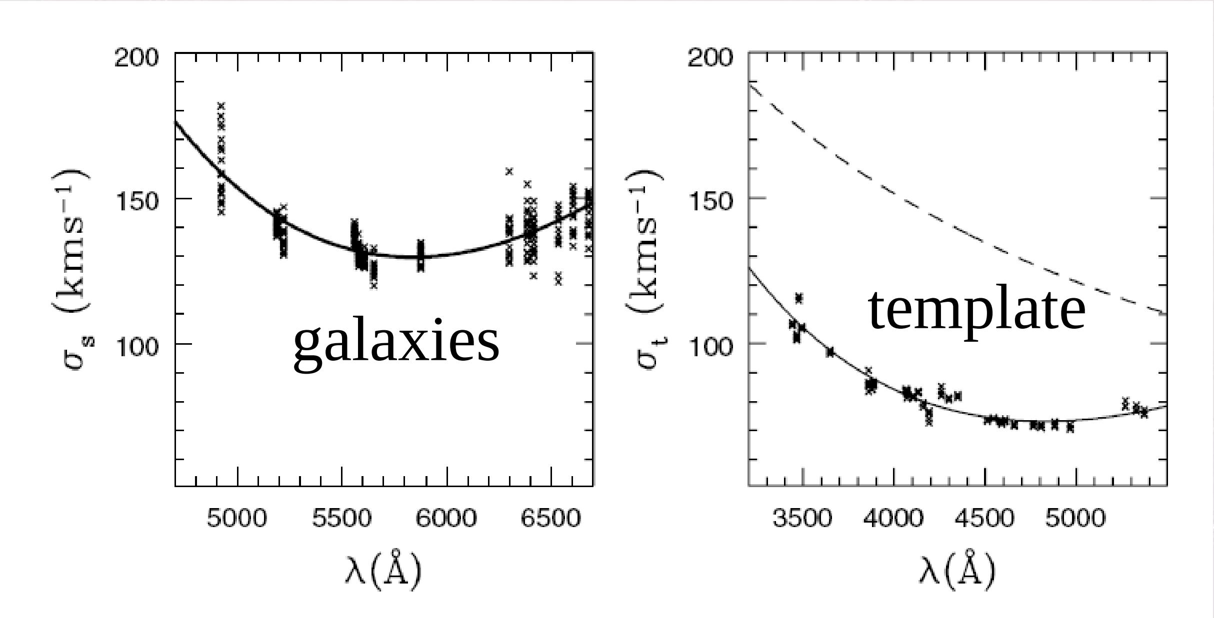
$$O(\lambda) = L(\lambda) \circ P(c[\lambda/\lambda_o - 1])$$

- The Fourier transform of a convolution is a product. Thus, the Fourier transform of P can be obtained from the ratio of the Fourier transforms of O and L. For this reason several common methods to derive velocity dispersions rely on working in the Fourier space (FQ, FCQ).

Kinematics : velocity dispersion

- For nearby galaxies one can observe galaxies and stellar templates (stars in our galaxy) using the same setup (the difference in redshift is small). For high redshift galaxies one has to use *synthetic* templates. Generating synthetic templates requires a well-measured variation of the instrumental width with wavelength. This instrumental profile can be used to broaden higher resolution template to the resolution of the galaxy observations.

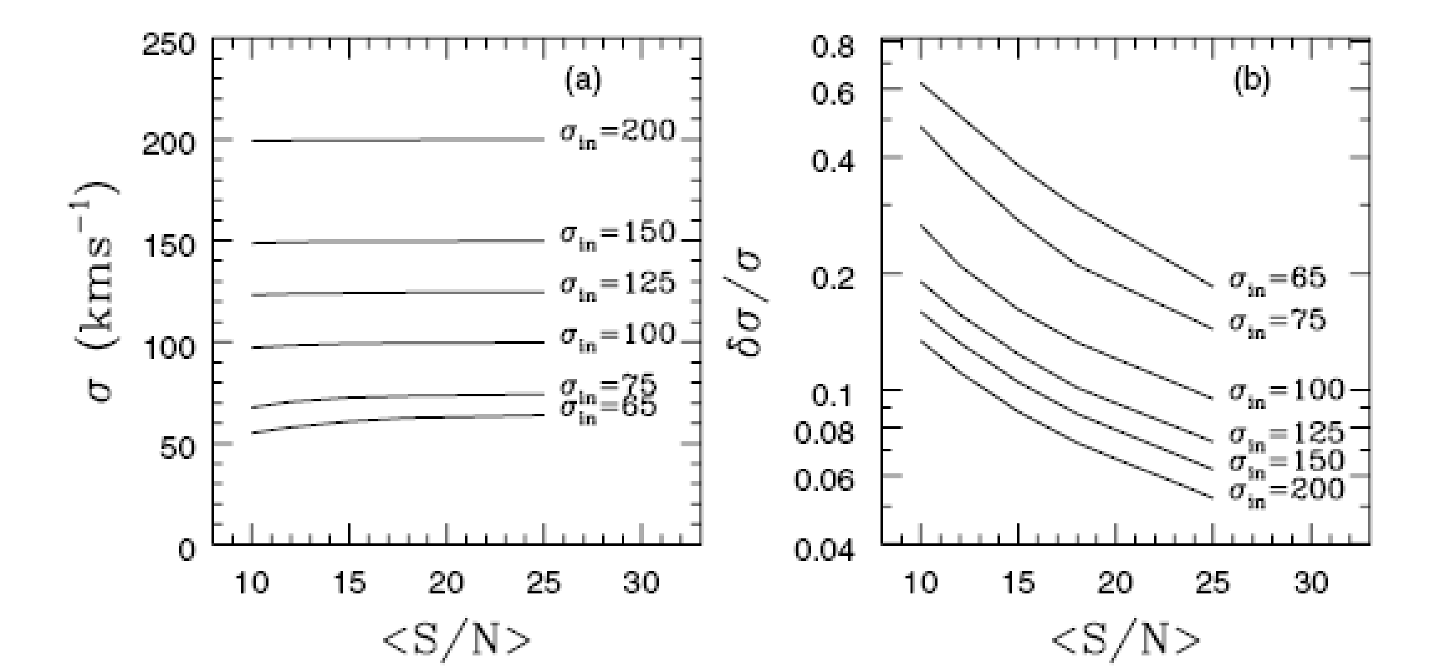
$O(\lambda) = L(\lambda) \circ T(\lambda) \circ P(c[\lambda/\lambda_o - 1])$ T is the instrumental profile



Treu et al. 2001 MNRAS 326, 221

Kinematics : velocity dispersion

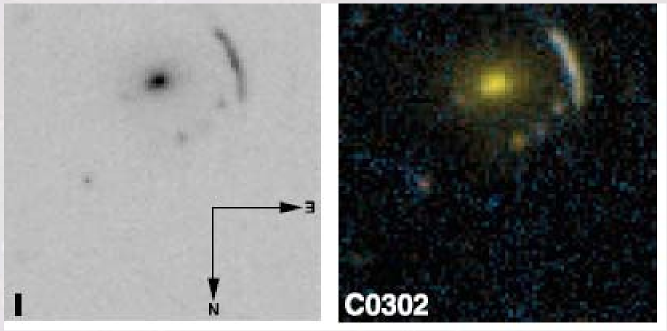
- The measurement error in velocity dispersion depends on the value of the dispersion, the instrumental width, and the type of the template and how well the template matches the line strengths and line ratios in the galaxy.

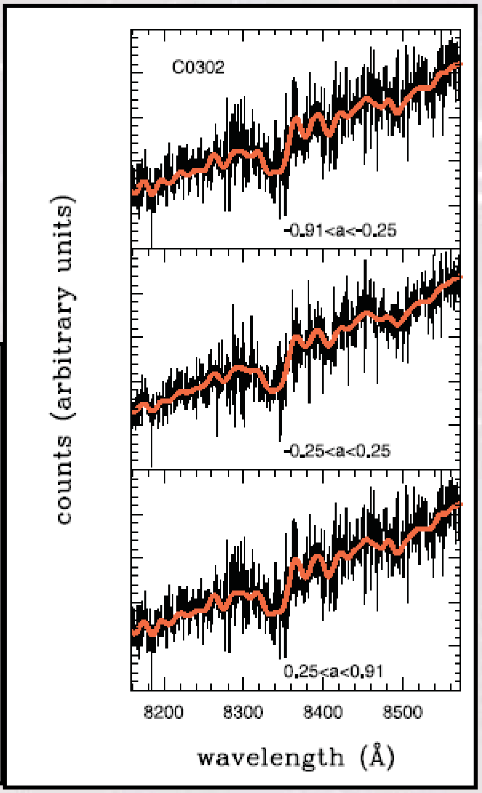


Treu et al. 2001 MNRAS 326, 221

Kinematics : velocity dispersion

- These difficulties generally limit the redshift to values below 1 but few velocity dispersion measurements have been done for z>1.





Keck/ESI spectrum of a I=19.86 elliptical at z=0.938 with σ=250 km/s. The integration time has been 6.5 hours (seeing 0.8”).

See Treu & Koopmans 2004 ApJ 611, 739

Summary

1. Spatially resolved studies at redshift 1 require angular resolution << 1 arcsec.
2. Space is for imaging, spectroscopy is best from the ground (but sometimes one needs space, see BH searches with STIS).
3. Morphologies are uncertain, one uses simplified morphology
4. Dynamical measurement of masses, some structural info
5. Emission lines kinematics can be done to z=2.4
6. Absorption line velocity dispersions can be measured to z=1.2