The relation between stars and gas in distant galaxies

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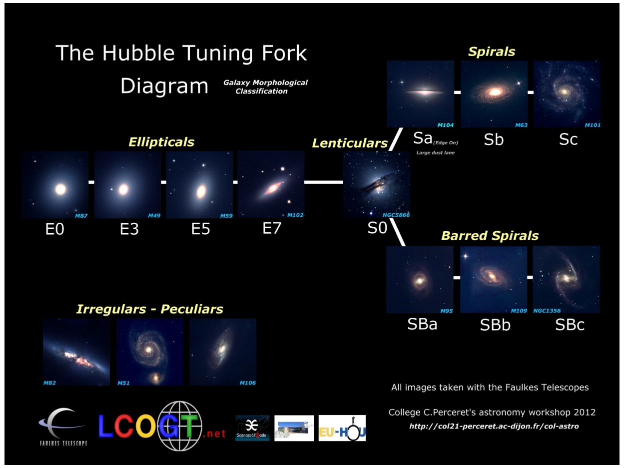
Introduction

- Classification of galaxies through different methods
- Scaling relations defined by local galaxies and their applicability to the extended universe
- Quantifying the parameters of a distant galaxy to test locally derived scaling relations

Classification of galaxies

- Hubble (1926) looked at galaxy morphological features
- Led to three groups: ellipticals, spirals, and irregulars
- Later research would extend the scheme:
  - Sandage and Bedke (1994) with lenticulars
  - de Vaucouleurs (1959) with a more comprehensive classification of spiral galaxies: an emphasis on the rings and lenses of spirals

The Hubble Sequence



Astronomie au college PERCERET (2012), 'HUBBLE TUNING FORK DIAGRAM', http://col21-perceret.ac-dijon.fr/col-astro/spip.php?article9

Fundamental galactic dynamics

- Quantifying galaxies with *energy*, *mass*, *angular momentum* instead of morphology
- Angular momentum (AM) provides an indication of the formation and potential evolution of a galaxy
  - Feeble (1969): protogalactic acquisition of AM
  - Fall and Efstathiou (1980) and Mo et al. (1998): modelling the discs and halos of spirals
  - Romanowsky and Fall (2012): ellipticals, spirals and their relation between AM and mass

Scaling relations

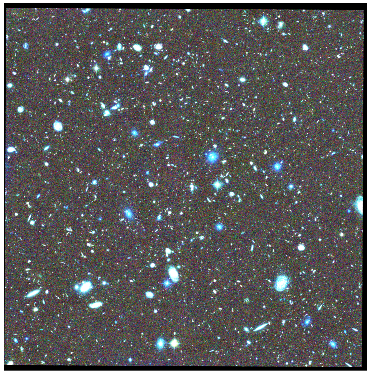
- Relationships between the physical properties of galaxies
  - Tully-Fisher (1977): the stellar velocity vs. stellar mass in spirals
  - Faber-Jackson (1976): velocity dispersions vs. stellar mass in ellipticals
- Relations reflect the local universe as they were calibrated with nearby galaxies

Are locally calibrated scaling relations valid and applicable for the high-redshift universe?

The Hubble Ultra Deep Field (1)

- The Hubble Space Telescope (HST)
  - Initial HDF in 1996 revealed sources with $z>1$
  - HUDF project in 2006 contained sources $z\sim4$–7
- The Multi-Unit Spectroscopic Explorer (MUSE)
  - Observed the HST HUDF region
  - Produced a composite 3D data cube

The Hubble Ultra Deep Field (2)



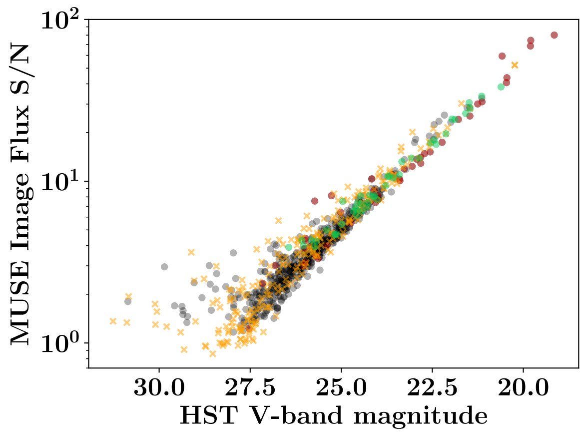
HST

MUSE

Galaxy extraction

- Analysing the MUSE data cube
  - Objects (stars and galaxies) identified
  - “Segmentation map” to discern between objects
  - Extracting a square region around object
- Sample reduction using HST derived parameters
  - Redshifts: z<0.3
  - Magnitude: m>26.0

Sample of galaxies



Gas dynamics

- Applying segmentation map to data to create a single spectra
- [OII] emission doublet isolated and a Gaussian function applied

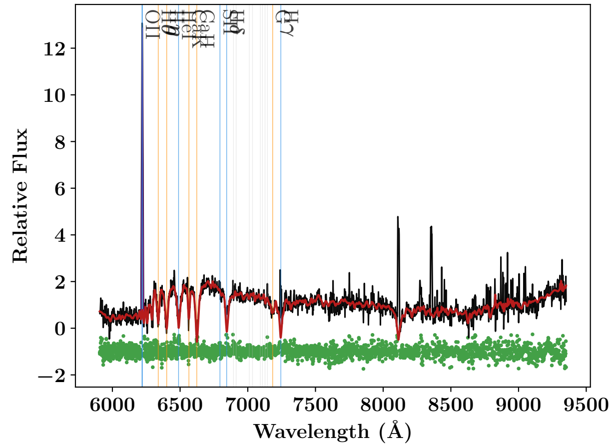
$$f_{OII} = cx + \frac{I_1}{\sqrt{2\pi}\sigma} \exp \frac{-(x-\lambda_1)^2}{2\sigma^2} + \frac{I_2}{\sqrt{2\pi}\sigma} \exp \frac{-(x-\lambda_2)^2}{2\sigma^2} \quad \text{with} \quad \sigma = \sqrt{\sigma_{gal}^2 + \sigma_{inst}^2}$$

- Obtained velocity dispersion σ represents the galactic gas dynamics

Stellar dynamics

- Considering absorption features of the spectrum
- Applying template fitting routine, pPXF
  - Combines multiple different spectral templates
  - Ability to return the velocity and velocity dispersion of the galaxy

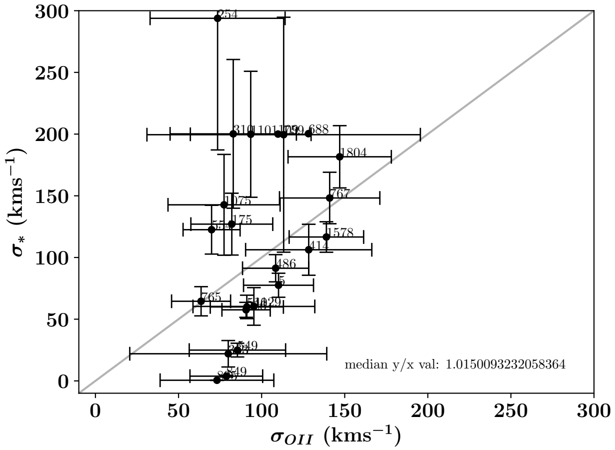
Galaxy spectra



Validity of fitting routines

- Stellar spectra fitting can utilise different spectral template sets
- Comparing [OII] velocity dispersions from doublet fitting with values provided by a pPXF gas fitting
- Obtaining fractional uncertainties vs. S/N through perturbing a single spectra with normal noise

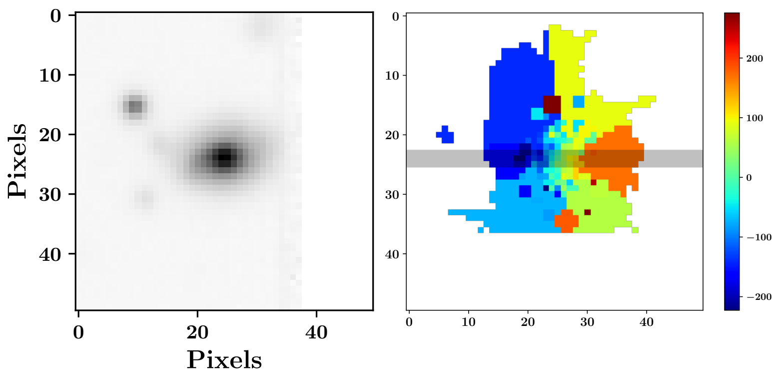
Comparison of dynamics



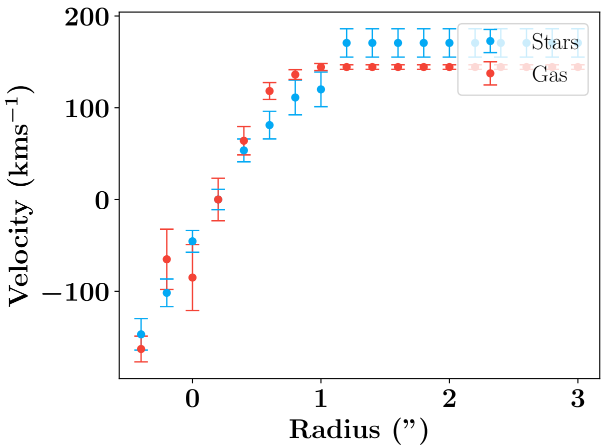
Voronoi tessellation

- Splitting a galaxy up into specific areas which are based on achieving a certain S/N
- Fitting for the stellar and gas dynamics in each individual area to produce a map of the velocities and velocity dispersions
- Production of rotation curves for a galaxy to demonstrate the galactic dynamics

Tessellated maps



Rotation curve



Summary

- Galaxies can be classified by fundamental parameters and not just by their morphologies
- Scaling relations between galaxy parameters are calibrated in the local universe
- Testing scaling relations for the extended universe requires deeper optical and spectroscopic data
- Fitting for spectroscopic features quantifies the current dynamics in a galaxy so comparisons can be made

Any questions?