50 years of galaxy evolution

• A perspective
• Using stellar masses and ESO/VLT
• Looking forward
Bird's-eye view of galaxy evolution

70s:
• Dark matter
• Structure of galaxies + Tully-Fisher, Faber Jackson

80s:
• Large scale structure/clusters and hot gas
• Flows
• Mergers (including IRAS Ulirgs)
• Lensing
• Galaxy structure and gastrophysics

Low z: Mostly low z
90s:
- Large scale structure
- Galaxy evolution
  - Z=0 to z=1 CFRS
  - Z=3: Lyman Breaks
  - Z=5 and above
- Evolution of clusters (Xray + optical)
- Super massive Black Holes

2000s:
- SDSS
- Major surveys – quantify galaxy evolution
- Mass selected samples + serious models
What was ESOs contribution?

1. Stars orbiting the Milky Way black hole
2. Accelerating Universe
3. First Image of an Exoplanet
4. Gamma-ray bursts – the connections with supernovae
5. Cosmic temperature independently measured
6. Oldest star known in the Milky Way
7. Flares from the supermassive black hole at the center of the Milky Way
8. Direct measurements of the spectra of exoplanets and their atmospheres
9. Richest planetary system
10. Milky Way stellar motions
Some highly cited ESO papers on galaxies/galaxy evolution

1980s


• Shaver et al. 1983 The galactic abundance gradient (735)

• Prevot, Lequeux, et al. 1984, The typical interstellar extinction in the Small Magellanic Cloud (309)

1990s (z>0.0001)

Caon, Capaccioli, D’Onofrio 1993, On the Shape of the Light Profiles of Early Type Galaxies (414)

Jorgensen, Franx, Kjaergaard et al. 1996, The Fundamental Plane for cluster E and S0 galaxies (393)

Bergeron & Boisse, 1991, A sample of galaxies giving rise to Mg II quasar absorption systems (356)

2000s

CDFS, Goods, Cosmos, VVDS survey papers (multi wavelength, multi-observatory)

Bell et al, 2004, Nearly 5000 Distant Early-Type Galaxies in COMBO-17: A Red Sequence and Its Evolution since z=1 (618)

Thomas et al 2005, The Epochs of Early-Type Galaxy Formation as a Function of Environment (597)


Le Floc'h et al. 2005 Infrared Luminosity Functions from the Chandra Deep Field-South: The Spitzer View on the History (500)

Giacconi et al 2001 First Results from the X-Ray and Optical Survey of the Chandra Deep Field South (399)

Daddi et al 2007, Multiwavelength Study of Massive Galaxies at z~2. I. Star Formation and Galaxy Growth (351)

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Combo-17: 2.2m imaging, with medium band filters
Using (stellar masses) for galaxy evolution

Before 2000, most analyses based on luminosities

![Graph showing mass-to-light ratio versus age](image)
Using (stellar masses) for galaxy evolution

We only have a stellar mass for the Milky Way – where we can count the stars

Extragalactic: micro-lensing (for “real” astronomers)

or …
Using (stellar masses) for galaxy evolution

We only have a stellar mass for the Milky Way – where we can count the stars

Extragalactic: micro-lensing (for “real” astronomers)

or …

Modeling … (IMF, stellar population model, metallicities, star formation, history, extinction curve, distribution of dust and stars, emission lines …)
The saving grace:
THE MASS ASSEMBLY AND STAR FORMATION CHARACTERISTICS
OF FIELD GALAXIES OF KNOWN MORPHOLOGY

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ABSTRACT

We discuss a new method for inferring the stellar mass of a distant galaxy of known redshift based on the combination of a near-IR luminosity and multiband optical photometry. The typical uncertainty for field galaxies with $I < 22$ in the redshift range $0 < z < 1$ is a factor of 2. We apply this method to a newly constructed sample of 321 field galaxies with redshifts and Hubble Space Telescope morphologies enabling us to construct the stellar mass density associated with various morphologies as a function of redshift. We find a marked decline with time in the stellar mass associated with peculiar galaxies accompanied by a modest rise in that observed for elliptical galaxies. The result suggests that peculiar galaxies decline in abundance because they transform and merge into regular systems. The star formation rate per unit stellar mass indicates that massive systems completed the bulk of their star formation before redshift 1, whereas dwarf galaxies continue to undergo major episodes of activity until the present epoch.

Subject headings: galaxies: evolution — galaxies: fundamental parameters — galaxies: stellar content
Fig. 2.—Integrated stellar mass density for galaxies with $10.5 < \log M_{\text{star}} < 11.6$ as a function of redshift and visual morphology. The shaded regions show the predictions of the mass density in peculiar and elliptical galaxies from the simple merging models described in the text.

Fig. 3.—Specific star formation rate $R$ for the galaxies in the sample. The three lines show orthogonal least-squares fit to the three redshift ranges indicated. The fit parameters are shown in the lower left corner. The right-hand panel shows the doubling time in Gyr, assuming constant star formation. Arrows show $2\sigma$ upper limits for galaxies with no detected [O II] emission.
Bell et al:

“When we account for the change in stellar mass-to-light ratio implied by the redshift evolution in red galaxy colors, the COMBO-17 data indicate an increase in stellar mass on the red sequence by a factor of 2 since z=1”.
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The mass in dead galaxies increases with time; the mass in star forming galaxies remains the same.
Where does the VLT come in?

We knew about Lyman breaks, SFR(z), z=5 galaxies, Ly alpha emitters, etc.
K20 survey (Cimatti et al)

Deep FORS spectroscopy on a K selected sample
Z>2: selection in observed optical = rest-frame UV
Need rest-frame optical selected samples at z>2

Requires:

• Deep Near-IR imaging (ISAAC)
• Mostly photometric redshifts (multi-wavelength)
Mass selected galaxies $z \approx 2.5$  
I, J, K composite
Mass selected galaxies $z \approx 2.5$

B,V,I composite
Mass selected galaxies $z \approx 2.5$

I, J, K composite

V+I  K  VI, J K
Z>2 universe selected in the restframe optical

• Massive galaxy population dominated by red galaxies – just like the nearby universe ("bulges", disks, "early-types")

• Most too faint for spectroscopic follow-up
Low specific star formation
High specific star formation

\[
\log(\text{Stellar mass})
\]

\[
\log(1700 \text{ Angstrom luminosity})
\]
Small effective radius
Large effective radius

$log(\text{Stellar mass})$

$log(1700 \text{ Angstrom luminosity})$
2 surprises

• Dead galaxies evolve strongly since $z=1$
• Red & star forming and red & dead galaxies exist at $z=2$ and above
Surprise #3

• Massive galaxies with very low star formation exist at $z>2$ – but they are very small!

Daddi et al 2005
Trujillo et al 2004,06
Franx et al 2008
Van Dokkum et al 2008
Cimatti et al 2008
The dead galaxies that exist at $z=2-4$ are very different from those at $z=0$.

Galaxies have not read about passive evolution!
The Final Step

- Link galaxies by cumulative number density
The Final Step

- Link galaxies by cumulative number density
Patel et al. 12
Why should we believe any of this?

- Analyses depend strongly on "photometric redshifts" & stellar masses
- Spectroscopy required – in the Near-IR!
X Shooter spectrum of galaxy at z=1.8

Van de Sande 12
Lessons for the future

• In early days, ISAAC was truly innovative (image size, quality)
• Deep surveys (e.g., K20, Combo17, FIRES) made impact: depth and multiplex
Why were 8m-10m telescopes so successful?

- Area only a factor of 4 gain!
Why were 8m-10m telescopes so successful?

- Area only a factor of 4 gain!
- Throughput: factor 2-3
- Image quality: factor 2-4
- Multiplex: factor 4-50
- Total: factor 120-1500
Lessons for the future

• For ELT, the same will hold: area, throughput, multiplex, image quality, (wavelength coverage) are crucial
Lessons for the future:

• Synergy with other facilities crucial
Lessons for the future:

• Synergy with other facilities is crucial
• overlap ELT with JWST will be minimal
• VLT, Alma, Euclid
Happy Birthday!