HST’s Galaxy Evolution Imaging Surveys

Hans-Walter Rix
Max Planck Institute for Astronomy
Heidelberg
HST’s Imaging Legacy

• What Imaging Qualities of HST Matter?

• The Hubble Deep Field(s)

• The “Wedding Cake” in the CDFS:
  – GEMS
  – GOODS
  – UDF

• Whither?
Which of HST’s Imaging Qualities Matter Most for Galaxy Evolution Studies?

- Imaging depth?
- Angular Resolution?
- PSF stability?
- Surface brightness sensitivity?
- Color imaging at high spatial resolution?
- Optical + near-IR imaging?
HDF North and South

Williams et al 1996,...
HDF and the Cosmic Star-Formation History

Madau et al 1996

Connolly et al 1997
HDF and the Cosmic Star-Formation History

Madau et al 1996

Connolly et al 1997
Morphologies: Seeing Too Much Detail?

Abraham et al: The large fraction of peculiar/irregular/merging systems in the Hubble Deep Field suggests that by $I \sim 25$ mag the conventional Hubble system no longer provides an adequate description of the morphological characteristics of a high fraction of field galaxies.
Red galaxies in HDF-South

FIRES @ VLT: Franx,van Dokkum, Labbe, Foerster-Schreiber, Rix, Rudnick,..
Red galaxies in HDF-South

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The Extended Chandra Deep Field South: GEMS, GOODS, UDF
Field Size and the “Cosmic Average”

Somerville et al. 2004
Galaxy Evolution from GEMS
GEMS Highlights
Red Galaxies at z~1: “Dead” or Dusty?
Red/Dusty or Red/Dead?
(Bell et al. 2004b)

Pick thin redshift slice (0.7) to eliminate
• differential band-shifting
• differential \((1+z)^4\) dimming

Classification visually + concentration index

Present Epoch \(z \sim 0.7\)

[Graphs showing \(U-V\) vs. luminosity for different redshift ranges]
Red/Dusty or Red/Dead?

(Bell et al 2004b)

Pick thin redshift slice (0.7) to eliminate
- differential band-shifting
- differential $(1+z)^4$ dimming

Classification visually + concentration index

85% of the red sequence at $z \sim 0.7$ are early types,
i.e. `red and dead`

\[ a) \text{SDSS } z \sim 0; \text{ Automated} \]
\[ b) \text{GEMS } 0.65 \leq z \leq 0.75; \text{ Automated} \]
In Which Types of Galaxies do Most Stars Form?
• “Visual” morphologies
  – 6 eyes

• 2800A or 24mum as SF proxies (Wolf et al 2004; Bell et al 2005)

• At $M_v > -19$ and $z \sim 0.75$
  – $1/2$ the flux comes from seemingly normal spirals
  – 20% from visibly interacting systems

• only minority of UV flux from interacting systems at $z \sim 0.75$
  $\rightarrow$ drop in interaction rate unlikely cause for large drop in UV flux

UV-light contribution by
Galaxy type at $z \sim 0.75$
Did *anything* happen to the massive red galaxies since $z \sim 1$?

Steps towards determining a merger rate:

– Devise quantifiable definition of “ongoing merger”

– Estimate a timescale for this phase: *incidence* $\rightarrow$ *rate*

– Quantify how the ongoing merger changes the probability of entering sample: 
  *e.g. merger* $\rightarrow$ *star-formation* $\rightarrow$ *lumosity boost*
Dry* Mergers at z<0.7
Bell, Naab, HWR, et al 2005

Each progenitor is a Sp-Sp merger remnant

Recognizable:
  i) <5 kpc separation
  ii) Asymmetries / broad tails

For ~250 Myr independent of merger details (mass ratio, pericenter, etc)

* No cold gas, no ensuing star-formation
Actually observed “dry” mergers at $z<0.7$ in GEMS
Actually observed “dry” mergers at $z<0.7$ in GEMS

- 14 (7 pairs) / 400 “merging” galaxies $0.2<z<0.7$
- 250 Myr timescale
  $\Rightarrow \sim0.9+/-0.4$ mergers / massive red galaxy since $z\sim0.7$ with mass ratios 4:1 --- 1:1
How long-lived are bars?

Scenarios

– Bars are long-lived \( \sim t_{\text{Hubble}} \)
  • Slow-down and growth in cuspy halos?

– Bars form and dissolve repeatedly

– Bars are a recent phenomenon
  • \( f_{\text{bar}} \sim 5\% \) before \( z=0.6 \) Abraham et al 1999
Are Galactic Bars Long-Lived?
Bar Frequency in GEMS/GOODS
Jogee et al. 2004

\[ z = 0 \text{ (OSU sample)} \]

\[ z = 0.6-1.3 \text{ (} T_{\text{back}} = 6--9 \text{ Gyr) } \]
When

- measured at the same rest-frame $\lambda$ (B/V)
- simulating differential detectability

Bar frequency did not significantly change since $z \sim 1.2$ (25%)

$\Rightarrow$ Longevity: $T_{\text{lifetime}} \times N_{\text{re-form}} > f_{\text{bar}} \times t_{\text{Hubble}}$
How did Galaxy Disks Grow?
Barden et al 2005, Ravindranath et al 2004

What to expect?
At least half of present-day disks stars formed since z~1

Higher SFRs $\Rightarrow$ higher surface brightness

Simplest scaling for the size *at a given mass*:

Mo, Mao, White: $R_{\text{exp}}(M_*) \sim M_*^{1/3} \lambda m_d^{-4/3} j_d H(z)^{-2/3}$
Size – Luminosity Relation of Disks (n<2) in GEMS
Barden et al 2005
Evolution of (Disk) Galaxy Sizes

- Ferguson et al 2004
- Ravindranath et al 2004
- Barden et al 2005
- Trujillo et al 2006
- Somerville et al 2007

Issues:
  - UV vs optical size
  - Size ($z | L_{UV}$) vs Size ($z | M_*$)

- “Naive” scaling $H^{-2/3}$ fails
- Modelling that accounts for DM halo concentration evolution works
- Inside-out growth seen in data
GOODS: Highlights

- Supernovae
- “Legacy”
- Faint star-formation at z~3-5
- Morphology
Giavalisco et al 2004
Statistics of projected ellipticities + random viewing angles

Much of (UV) SF occurs in (distorted) disks?

Shapes of Star-Forming Galaxies at $z \sim 3$
Ravindranath et al 2006
HST Sizes and Morphologies at $z >> 1$

- NICMOS: in HDF and other fields

Very massive, ultra-dense galaxies whose present-day counterparts cannot be identified??

Mean Mass Densities of Galaxies at $z \sim 2-3$
UDF
Which of HST's Imaging Qualities Matter?

- Imaging depth?  
  Most High-z science, SN
- High-rez morphology?  
  Mostly to z~1
- PSF stability?  
  Sizes, Host galaxies
- High-rez. color imaging?  
  AGN Host galaxies
- Optical + near-IR imaging?  
  + NICMOS impact limited
  + more ground-based
Whither?

WFC3