Star Formation in Field Galaxies since $z=1$

A quiescent, mass-dependent history

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... and thanks so much for inviting!!!
I. Why bother?
Co-moving star formation rate density declined by ~x10
proposed: driven by increase of galaxy merger rate with z

Mass dependence:
massive galaxies formed bulk of stellar and early, less massive galaxies formed on longer timescales
Understanding star formation on galaxy-wide scales

(evolution of light and chemistry in the Universe, illuminates DM, the evolution of clustering, cosmology, etc.)

Theory:
- no complete understanding on small scales,
- gas dynamics: cooling/accretion, feedback, winds, ...
- CPU /resolution limits in ‘true’ cosmological simulations
- semi–empirical treatment (Schmidt Law or similar);
  efficiency, feedback, timescales, etc. at z>>0?

Observations:
rapidly improving, but still no comprehensive picture at z>>0:
  Starbursts? Mass dependence?
II. New deep multiwavelength surveys: a more complete view
C. Willmer

AEGIS: The All-Wavelength Extended Groth Strip International Survey

- DEEP2: Keck / DEIMOS spectra: ~10,000 precision redshifts, galaxy kinematics
- HST V, I (700 sq arcmin - 2x GOODS)
- Very deep:
  - Spitzer (IRAC, MIPS)
  - GALEX (NUV, FUV)
  - Chandra ACIS
  - VLA 20cm
- Ground-based deep U- to K-imaging

aegis.ucolick.org


PRESS RELEASE

ApJ SPECIAL ISSUE

HTTP://AEGIS.UCOLICK.ORG

DATA RELEASE AUG 2007
A more detailed view of star formation properties

1) Fiducial **star-forming** galaxies:
   - 24µm sources, or blue emission line galaxies (~2/3 of sample)

2) Galaxies not detected in 24µm or emission lines:
   - red sequence, early-types not significantly star-forming (~1/3 of sample)

3) Galaxies with no detection in 24µm, but weak emission lines:
   - red sequence, 2/3 early-types, large fraction **LINERs/AGN**; (<20% of sample)
III. The “Main Sequence” of star-forming galaxies

and how it tells us how SF mostly happened
The majority of star-forming galaxies form a defined sequence with a limited range of SFR at a given stellar mass and redshift. 

\[ \text{SFR} \sim \pm 0.3 \text{ dex (1}\sigma) \]

“Normal” star-forming galaxies, – prior to quenching of star formation –?
“Main Sequence” found to $z > \sim 1$ for different tracers of SFR, stellar mass larger mass range

Elbaz et al. 2007
$z=1$, Spitzer 24um (GOODS)

Zamojski et al. 2007
$z=0.7$, GALEX/COSMOS

Brinchmann et al. 2004
(SDSS, $z \sim 0$)
A defined Main Sequence with similar range of SFR to z~1:

1) Limit on the amplitude of SFR variations/starbursts:
   Galaxies are 2/3 of the time within a factor of ~2 of their average SFR at that z
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Cox et al. 2006
A defined Main Sequence with similar range of SFR to $z \sim 1$:

1) Limit on the amplitude of SFR variations/starbursts:
   Galaxies are 2/3 of the time within a factor of $\sim 2$ of their average SFR at that $z$ (© limit to effect of mergers on SF)

2) Range of $\log$(SFR) constant to $z \sim 1$,
   MS ZP evolves with $z$:
   dominant mode of SF since $z \sim 1$ is apparently a gradual decrease of SFR, not evolving role of starbursts
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3) LIRGs at z~1 are massive galaxies in their normal high SFR, not strong starbursts like local LIRGs
IV. Size matters: mass dependence of SF histories
billions of years ago

big galaxies

rapid star birth & gas consumption

(image: Driver 1998)

today
	small galaxies

slow star birth & gas consumption
Assumption of old age for all galaxies: $t_d < t_{\text{Univ}}$, simultaneous starbursts for >50% of galaxies at $<10^{10}M_\odot$, $z=1$

Implausible, and inconsistent with gradual decline of SFR

only alternative: delayed onset of major star formation in part of less massive galaxies: $t_d \sim t_{\text{Univ}}$
New concept:

“Staged galaxy formation”:

less massive galaxies start major SF on average later, with $z_f$ more broadly distributed from high to low $z$. 
Today’s low-mass galaxies (<10dex Msun at z=0) had only a small fraction of today’s stellar mass at z~1
→ late onset of major star formation
V. A parametrization model
What drives the dominant gradual decline of SFR since $z \sim 1$?

Gradual processes like gas exhaustion?

A simple model to parametrize the mass-dependent evolution of SFR along the star-forming sequence.
Staged τ models: both τ and $z_f$ mass–dependent works consistent, but no proof of, a gas depletion scenario
Summary:
(NOTE: star-forming field galaxies)

1) Main Sequence of SF galaxies, limited range of SFR at a given M,z.
2) Limits amplitude of starbursts, merger effects on SFR.
3) Gradual decline of SF, not starbursts, dominant since z~1;
4) LIRGs at z~1 are mostly normal SF galaxies, not extreme starbursts

- New picture: high SFR often not brief starbursts, but early, gas-rich phase of a galaxy –

3) mass-dependent $\tau$ models: model of SFR vs M, z over $2/3\ t_H$

4) New scenario: less massive galaxies have longer SF timescales, and a delayed onset of major star formation
   $\rightarrow$ 2 effects contributing to “downsizing”: $\tau(M)$, $z_f(M)$
Prospects and future work
A new perspective to further our understanding of star formation:

Prior to quenching, star formation out of $z > 1$ follows a regular pattern

1) dominance of the same set of few physical processes?

3) A chance to identify the relevant physics

4) knowing normal SF: isolate effects of mergers, and quenching
Outlook (1): a new benchmark survey for SF, AGN, environments to $z>1.5$

GOODS, AEGIS: ~20,000 galaxies

MIPS Legacy survey ($t_{\text{exp}} \times 12!$) (in progress, PI M. Dickinson): deep 24 and 70$\mu$m, robust SFR to $z>2$, and to low SFR at $z<1$

DEEP3 (4+ yr, KeckII/DEIMOS), proposed Faber/Noeske
Data vs Semi-Analytic Models: GOODS & Millenium

Elbaz et al. 2007