Observations of star formation at z=1-3

Pieter van Dokkum (Yale)

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Star formation in young galaxies

By R. B. Larson
Yale University Observatory, Box 2023 Yale Station, New Haven, Connecticut 06520, U.S.A.

Some theoretical and observational reasons are given for regarding star formation as an induced process that proceeds in a series of bursts triggered by dynamical events, and it is suggested that intense bursts of star formation may have been particularly important for the early evolution of elliptical galaxies.
Measuring star formation

- Until recently: UV emission + dust correction
- Thanks to MIPS, Herschel: bolometric L
Measuring star formation

- Measuring IR luminosity important - particularly for massive galaxies

Whitaker et al. 2012
Cosmic star formation history

- Broad peak at $z=1-3$: formed about 50% of stars
- Cosmic star formation rate 10x higher than today

Hopkins & Beacom 2006; Bouwens et al 2008-20
Peak of the star formation history

- Question: were there more star forming galaxies, or did individual galaxies have higher rates?

- Need to study individual galaxies rather than cosmic averages
Peak of the star formation history

- Question: were there more star forming galaxies, or did individual galaxies have higher rates?
Nature of star forming galaxies

- In the local Universe, high SFRs typically associated with mergers
Nature of star forming galaxies

- At high redshift at least some, and apparently most, strong star formation occurs in disks

Apparently rotating gas disk at z=2.4 (Genzel et al 2006)
Nature of star forming galaxies

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Williams et al 2010
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- Dynamics often consistent with rotation in rest-optical, and dominated by outflows in rest-UV

  (e.g., Franx et al 97, Pettini et al 98-01, Erb et al 03-12, Shapley et al 08, Genzel et al 06-12, Forster Schreiber et al 10-12, Nelson et al 12, and many others)
In the past, things were more or less the same - but higher accretion rates onto more compact halos led to higher gas surface densities and therefore more rapid star formation.
Problem

• About 50% of stellar mass is in bulges and ellipticals - and these are the oldest stars

• Therefore, majority of stars formed at $z>1$ should end up in bulges and ellipticals at $z=0$
Second mode?

- Some disks probably undergo mergers, and/or develop bars and bulges

- However, elliptical galaxy formation probably triggered an entirely different mode of star formation (e.g., Naab, Ostriker, etc)
Another look at the z=1-3 Universe

- Sizes of star-forming disks: high degree of diversity among star forming galaxies at z>1

Nelson et al 2012
Another look at the $z=1-3$ Universe

- Sizes of star-forming disks: high degree of diversity among star forming galaxies at $z>1$

- Population of quiescent galaxies with very low star formation rates and very small sizes

van Dokkum et al 08
Compact, massive galaxies

- Probably the cores of today’s elliptical galaxies (based on number density arguments)
- Must have had extremely high gas densities, turbulence, and perhaps bottom-heavy IMF

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Near future

- **ALMA:**
  - Calibrate relation between SFR and gas density
  - Find obscured star-forming progenitors of compact galaxies
  - Map “true” star formation distribution

- Mapping of outflows and (possibly) cold streams (Rudie et al, etc)

- Kinematics of high redshift galaxies: circular velocities may be remarkably stable
• Velocity function of dark matter within 20 kpc

Weinmann et al, in prep; data: Bezanson et al 2011, 2012
A MODEL FOR THE FORMATION OF A SPHERICAL GALAXY

Richard B. Larson

(Communicated by P. Demarque)
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SUMMARY

Numerical calculations have been made for a model representing the collapse of an initially gaseous proto-galaxy and the concurrent transformation of gas into stars. The assumed turbulent motions of the gas are represented by a simple model consisting of discrete colliding clouds, and the star formation rate is assumed to be given as a simple function of the density and turbulent velocity of the gas. The gas clouds and the stars are then treated separately by means of fluid-dynamical equations derived from the Boltzmann equation. It is found that, by assuming reasonable values for the various parameters of the model, it is possible in this way to reproduce reasonably well the observed properties of spherical and nearly spherical galaxies.