Stochastic Star Formation in Low Mass Galaxies: a case study of DDO 210

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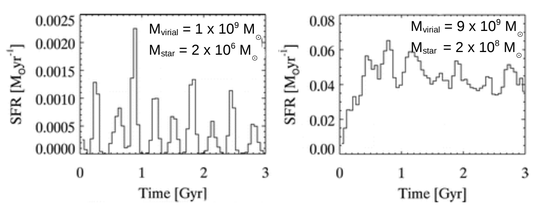
Abstract

To address the longstanding question of whether dwarf galaxies predominantly have bursty star formation histories requires a large sample of dwarf galaxies and an accurate tracer of star formation. Here we explore the utility of using two common tracers, Hα and the ultraviolet (UV). Hα and UV photons are primarily produced by massive stars, so stochastic effects come into play when the star formation rate (SFR) is so low that the upper mass end of the initial mass function (IMF) is not fully populated. We use Monte-Carlo simulations to explore these effects at a range of SFRs for a standard Chabrier IMF. We find that above SFRs of 0.001 $M_\odot yr^{-1}$ both the far-UV and Hα are reliable tracers of SFR. Below this value both indicators begin to show deviations, with Hα being more strongly affected. We explore the implications of these findings for the 11 Mpc Hα UV Galaxy Survey (11HUGS), a GALEX Legacy program designed to characterize the star formation properties of a local volume-limited sample. We highlight the dwarf galaxy DDO 210, which has a UV luminosity of 270 $L_\odot$, but no nebular Hα emission. While we cannot rule out a truncated star formation history for this galaxy, our simulations demonstrate that this Hα deficient galaxy could be forming stars at a constant rate of ~0.0002 $M_\odot yr^{-1}$.

1. Motivation

Simulations suggest that the lowest mass dwarf galaxies have bursty star formation histories due to the effects of supernova feedback.



SPH + N-body simulations of the star formation history of dwarf galaxies (Stinson et al. 2007, ApJ 667, 170)

To test this hypothesis we need:

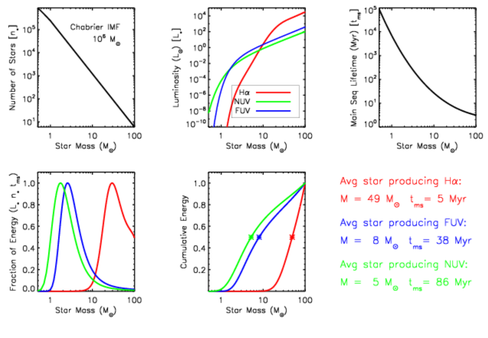
1) A large, complete, volume-limited sample of nearby galaxies such as the *11 Mpc Hα Ultraviolet Galaxy Survey* (11HUGS – see poster 095.04)

2) A good tracer of the instantaneous star formation rate (SFR)

Here we explore the accuracy of measuring galaxy SFRs using Hα and near- and far-ultraviolet (NUV, FUV) data from the GALEX satellite.

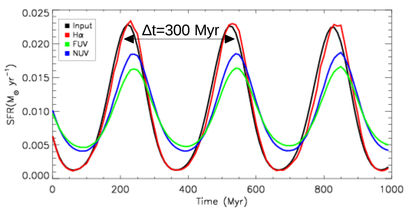
2. Background

Both the UV and Hα are good tracers of the instantaneous SFR because they are primarily produced in relatively short-lived massive stars.



In a galaxy forming stars continuously, the luminosity measured in a given band (Hα, NUV, FUV) depends on the SFR, the initial mass function (IMF), the distribution of luminosity as a function of stellar mass, and the main sequence lifetime of the stars. Note that the typical star contributing Hα photons is much more massive and short-lived than the typical star contributing to the NUV or FUV.

Hα has long been considered the best SFR tracer for studying starbursts because it is produced by the most massive and short lived-stars.

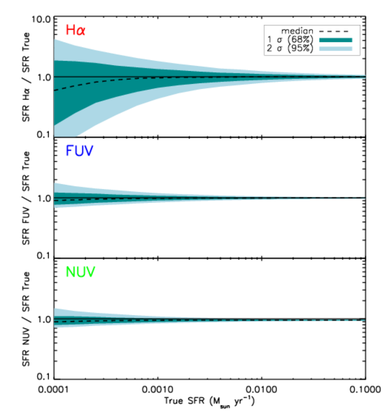


Comparison of a simulated galaxy's true star formation rate (black line), and the SFR which would be inferred from the object's Hα FUV, and NUV light (red, blue, green lines). The contribution of long-lived lower mass stars to the UV light causes the burst to appear damped and slightly shifted.

However, dwarf galaxies have such low SFRs that the upper mass end of the IMF may not be well populated.

3. Simulations

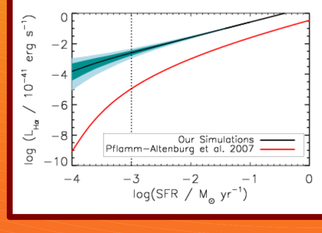
To understand the stochastic nature of star formation in dwarf galaxies we ran a large grid of Monte Carlo simulations. We drew stars randomly from a Chabrier IMF (2003, PASP, 115, 763) at a rate proportional to the instantaneous SFR and tabulated the Hα , FUV, and NUV luminosities of the stars over their main sequence lifetimes. Integrated luminosities were converted back to SFRs using standard calibrations and compared to the input SFR.



The SFRs inferred from Hα, FUV, and NUV luminosities are compared to the input SFR in our Monte Carlo simulations. One and two-σ contours are shown.

Poisson fluctuations in the number of very massive stars cause Hα to be an unreliable tracer of SFR below SFRs of 10^{-3} $M_\odot yr^{-1}$. The FUV and NUV are only mildly affected.

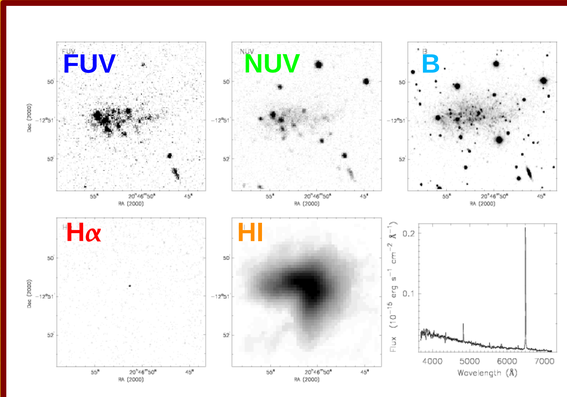
In these simulations we have not required that stars form only in clusters and that the maximum stellar mass formed is limited by the cluster mass, as suggested by Weidner & Kroupa (2005, ApJ, 625, 754). If this idea is correct, then the integrated galactic IMF is much steeper than and SFRs derived from Hα will be even more prone to stochastic fluctuations.



The conversion between Hα luminosity and SFR. In Pflamm-Altenburg, Weidner and Kroupa (2007, ApJ, 671, 1550) the conversion is non-linear because the maximum cluster mass formed scales with the SFR.

4. DDO 210

The dwarf galaxy DDO 210 (*Aquarius*) is the lowest luminosity (M_B = -11.05) gas-rich member of the local group (D=1 Mpc). Studies of its resolved stellar populations indicate that it has been forming stars at a rate of ~1.4 x 10^{-4} $M_\odot yr^{-1}$ over the last Gyr. (Lee et al. 1999, AJ, 118, 853). We expect statistical under-sampling of the IMF to be important in this tiny galaxy.



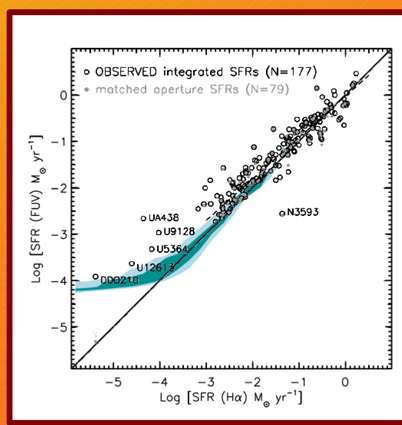
Multiwavelength observations of DDO 210. The top panel shows GALEX FUV and NUV images and a ground-based B-band image (van Zee 2000). The bottom panel shows deep Hα and HI images (van Zee 2000, Young et al. 2003) and a spectrum of the sole Hα knot (van Zee et al. 1997). The broad Balmer lines suggest that the Hα emission comes from the atmosphere of an evolved massive star rather than a HII region.

Curiously, this gas-rich galaxy has no HII regions, but copious UV emission. We infer that O-stars (M > 18 $M_\odot$) are absent either because star formation ceased 10-100 Myr ago, or because it is proceeding at such a low rate that the upper mass end of the IMF is not well populated. Most of the UV light arises from a collection of 10-15 B-stars.

We use DDO 210's FUV luminosity (L_{FUV} = 270 $L_\odot$) to infer a SFR of 1.8 x 10^{-4} $M_\odot yr^{-1}$, a little higher than the galaxy's past average, but well within the regime where statistical effects are important for Hα. However, even taking into account these effects, we would have expected to detect 4 +/- 2 O-stars. Thus we cannot rule out a very recent slow-down in the galaxy's SFR.

5. Implications

Hα is an unreliable tracer of SFR below SFRs of 10^{-3} $M_\odot yr^{-1}$. In this regime, the FUV is more accurate, although it has lower temporal resolution.



Comparison of SFRs computed from FUV and Hα data. The circles are measurements from the 11HUGs survey (see poster 095.04 for details). The green contours are from our simulations, which assume continuous star formation.

For characterizing the star formation histories of the smallest dwarf galaxies in the 11HUGS survey our UV data from GALEX are critical.