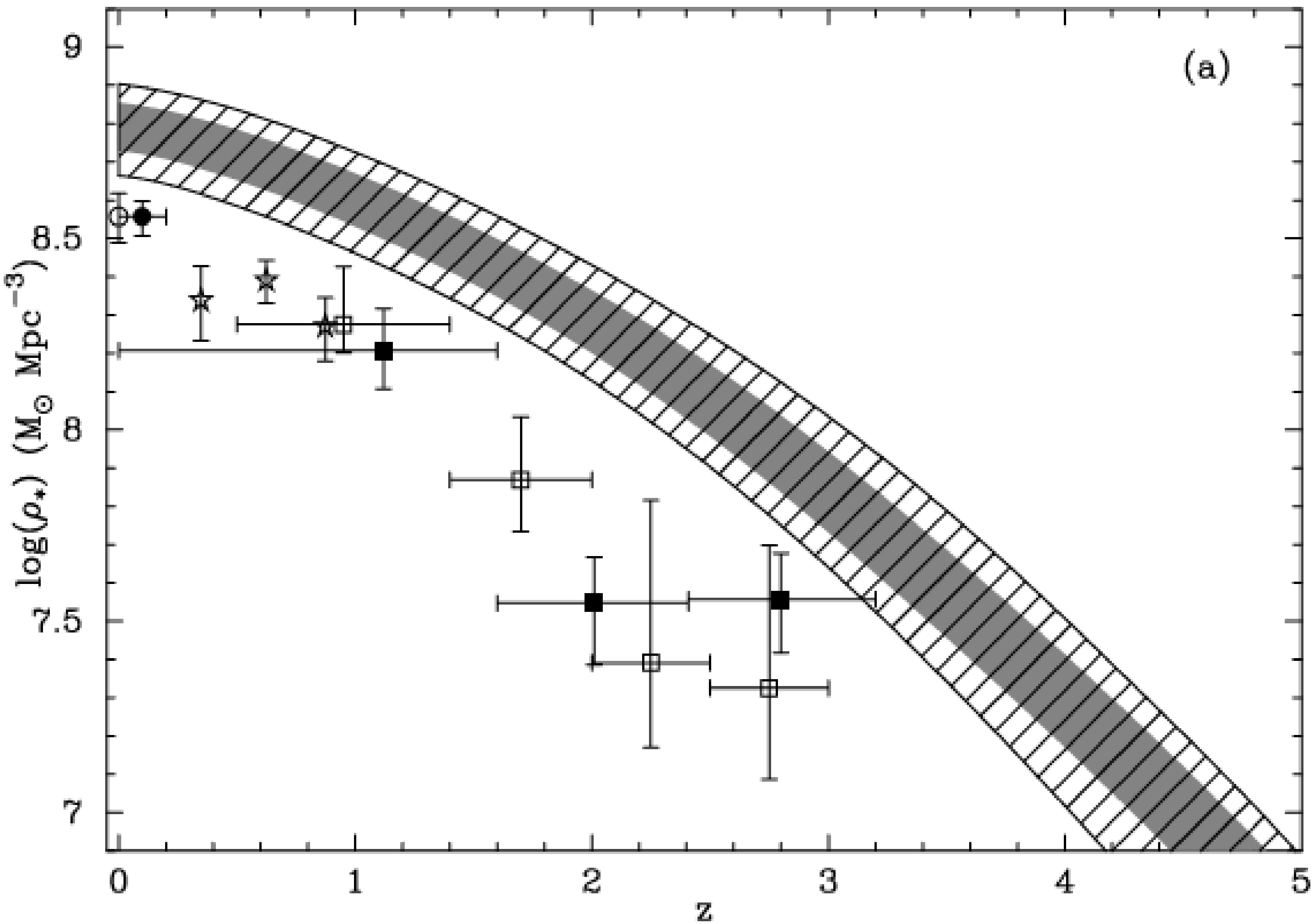
The Stellar Initial Mass Function in Star-forming Galaxies

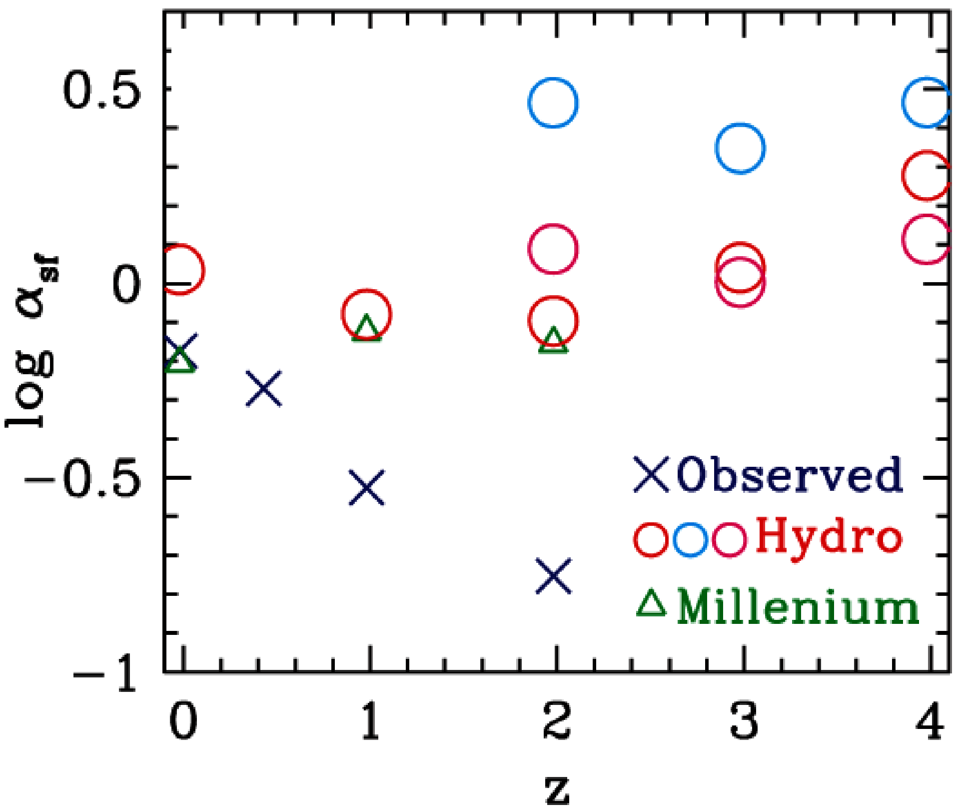
With Timothy M. Heckman

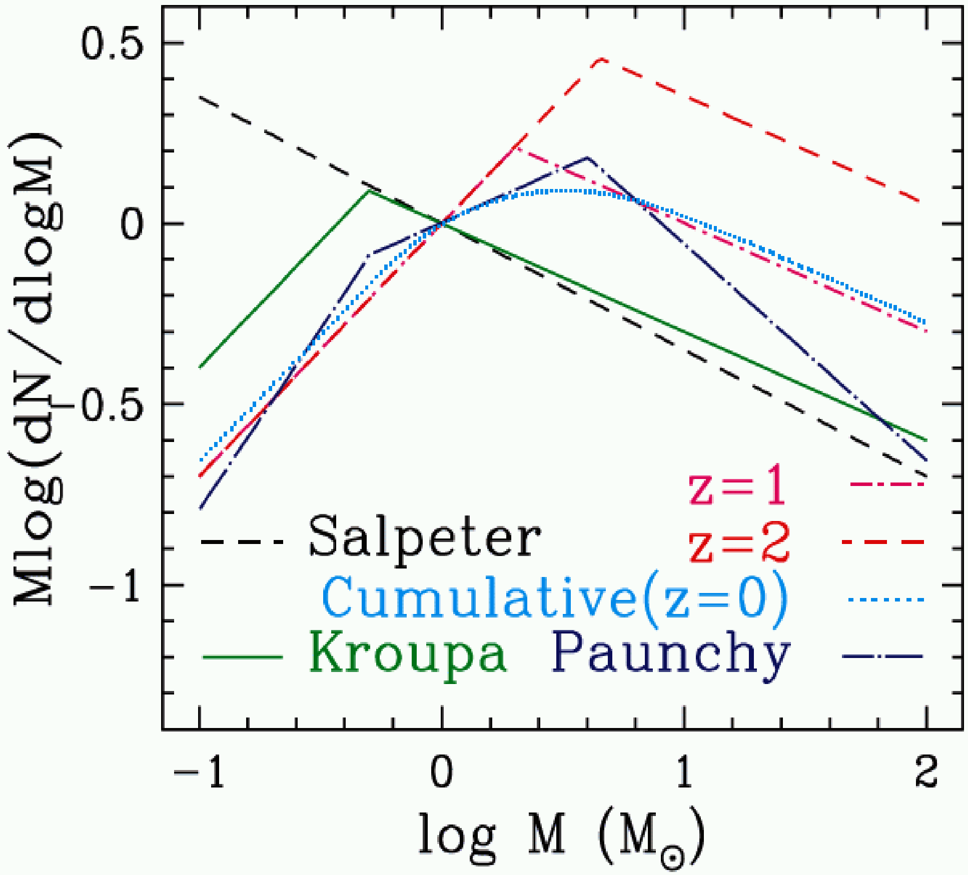
Hopkins & Beacom: There is tension when one tries to match observations of the comoving star formation rate density as a function of time with constraints on the total stellar mass density (see alsa Fardal et al for arguments using the EBL)



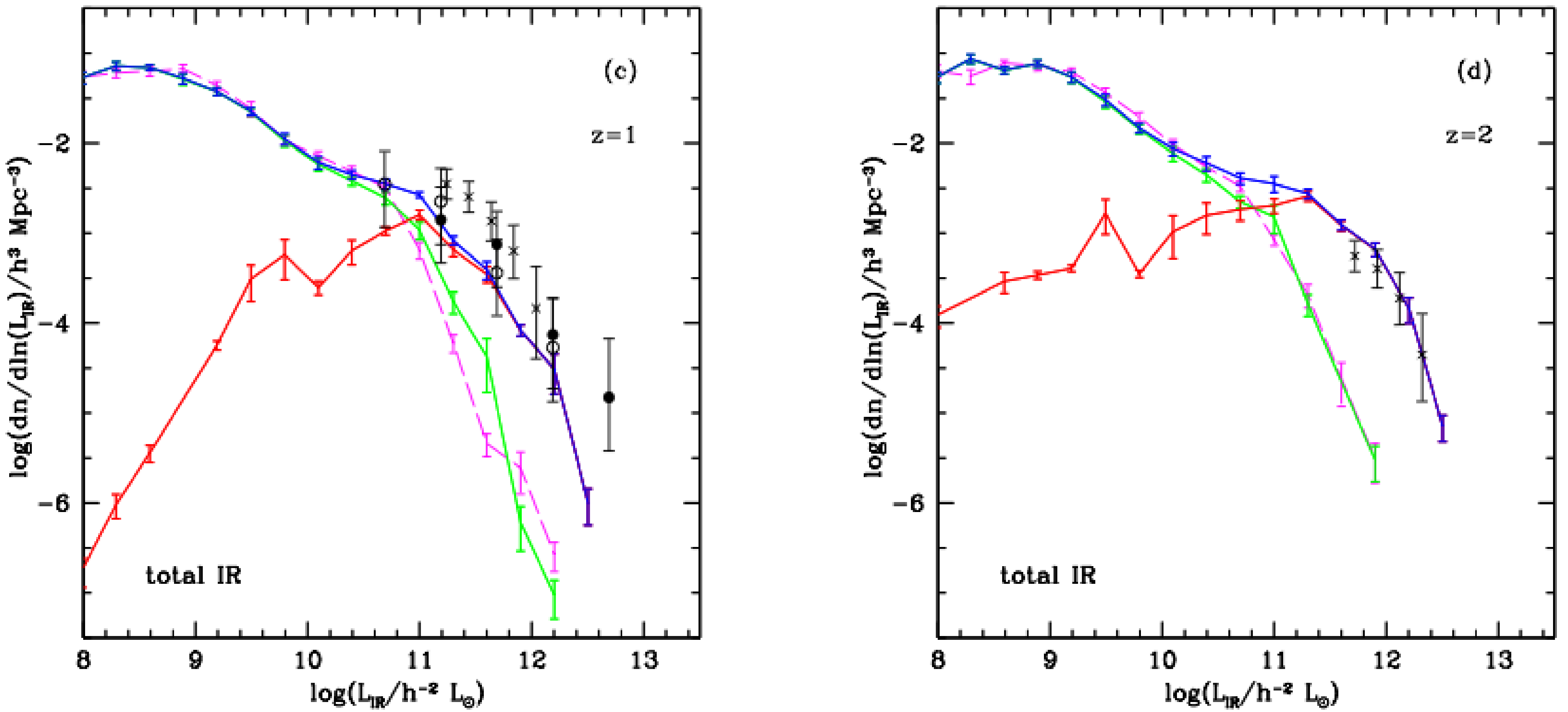
Romeel Dave has been struggling to understand the fact that at z=0, the characteristic star formation timescale for galaxies on the "blue sequence" is of order the Hubble time, but observations seem to show that it gets shorter and shorter at higher redshifts (i.e. Galaxies are ALL starbursts!) This doesn't fit ANY models!

Galaxies on the "blue sequence"





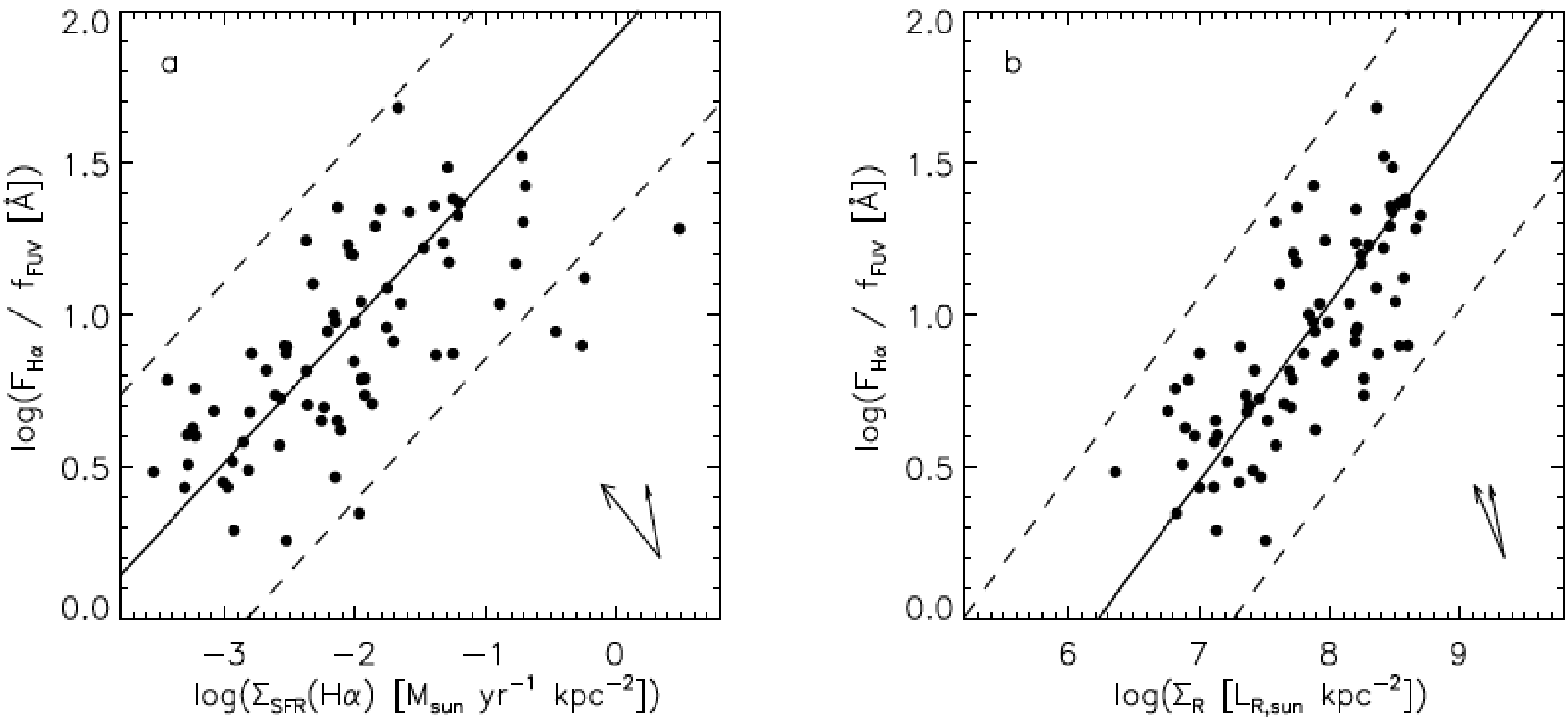
The **Durham** semi-analytic group have been failing for many years to reproduce source counts and luminosity functions at infrared wavelengths without appealing to a top-heavy IMF. Here are some recent plots from Lacey et al 2008.



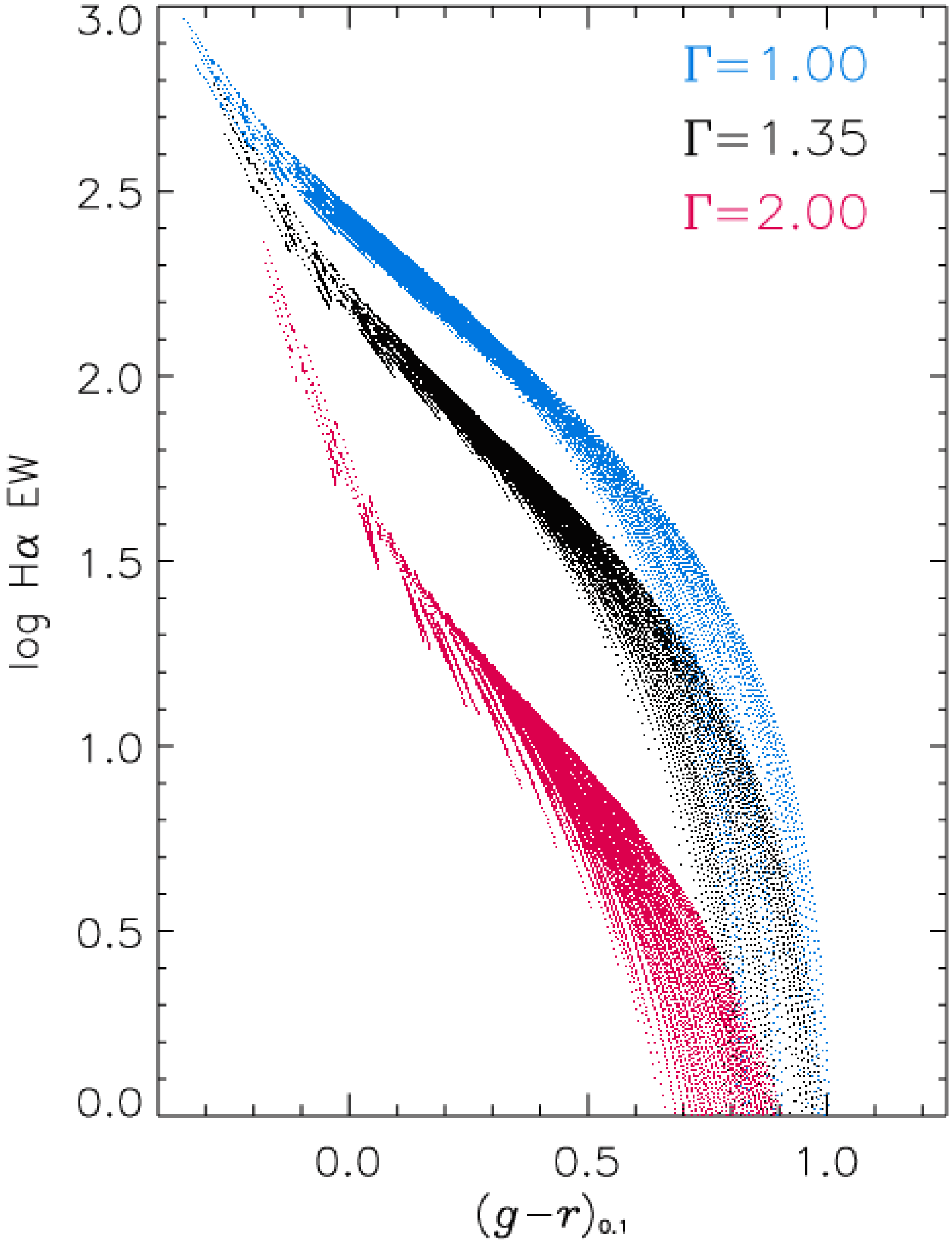
Can we find DIRECT EVIDENCE that the IMF varies?

(using diagnostics of integrated stellar populations)

Gerhardt Meurer 2008



respectively. What drives these strong correlations? The $F_{H\alpha}/f_{FUV}$ ratio is very sensitive to the O to B star ratio. The O to B star ratio is in turn affected by the parameters specifying the upper end of the IMF, and the star formation history. Other parameters that affect $F_{H\alpha}/f_{FUV}$ are the dust extinction, and the escape fraction f_{esc} of ionizing radiation. We posit that systematic variation of the IMF parameters are the most likely cause of the correlations seen in Fig. 3.



Hoversten & Glazebrook (2008) carried out a similar analysis using star-forming galaxies from the Sloan Digital Sky survey and found that more luminous galaxies had higher Halpha EW at fixed g-r colour. All quantities are corrected for dust extinction using the measured Balmer decrement plus "standard recipes".

We should also remember that stellar absorption lines will ALSO be sensitive to the IMF. Sensitivity of the Balmer absorption lines was studied by Gonzalez-Delgado, Leitherer & Heckman (1999). This can break key degeneracies – more massive stars mean that Balmer lines get WEAKER.

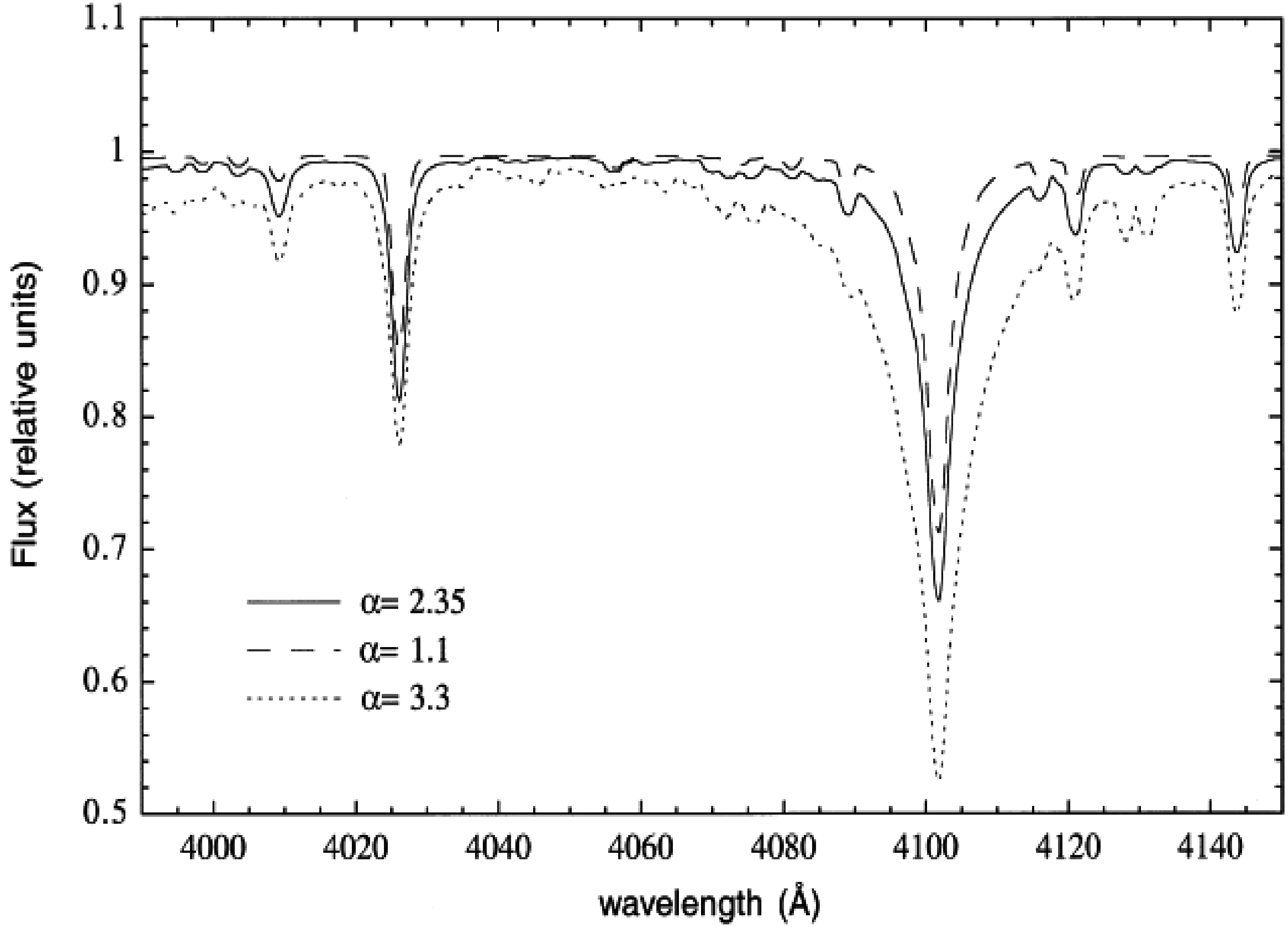
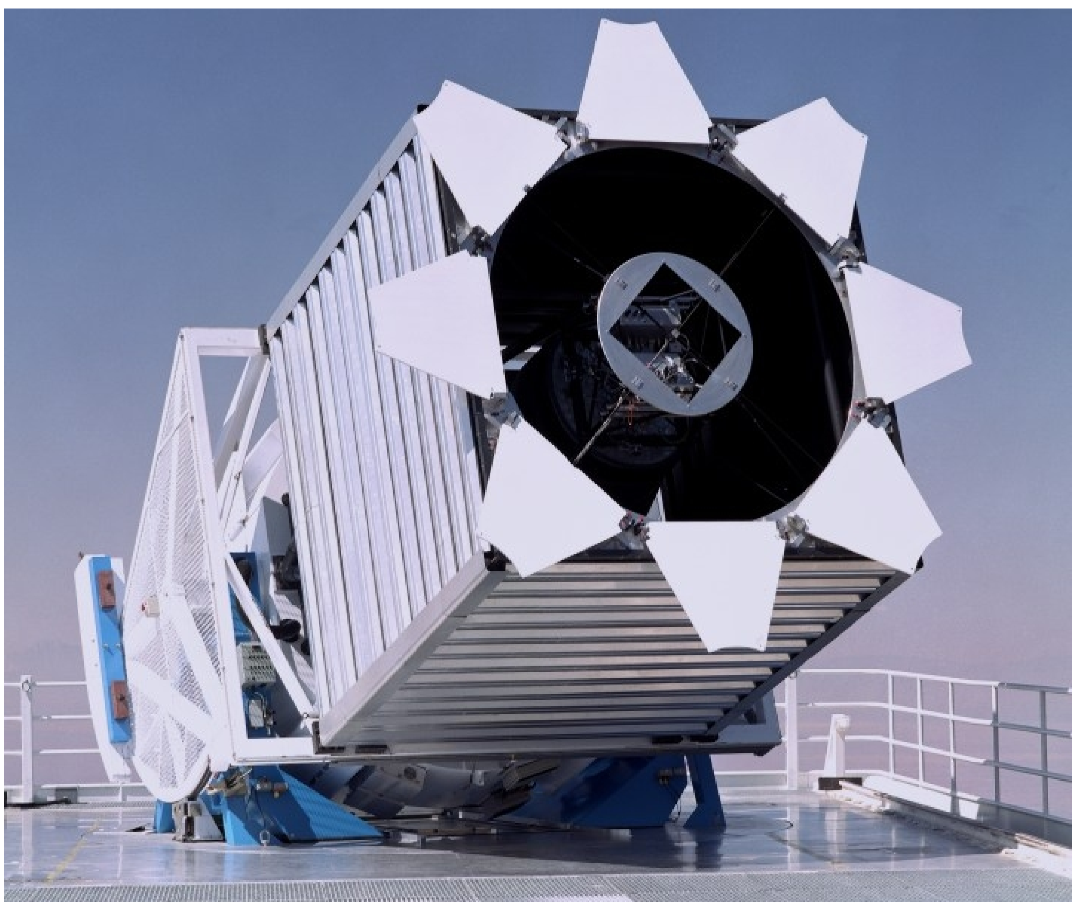
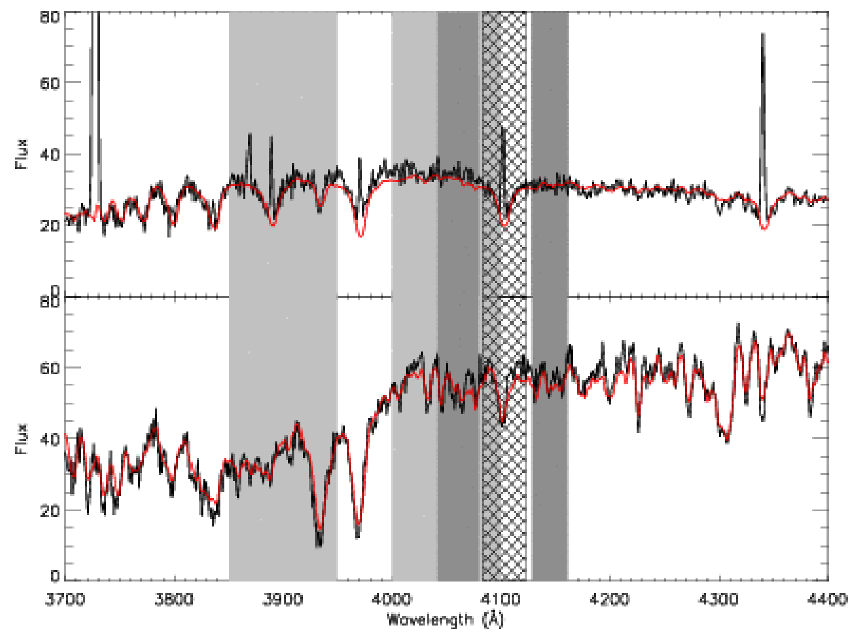


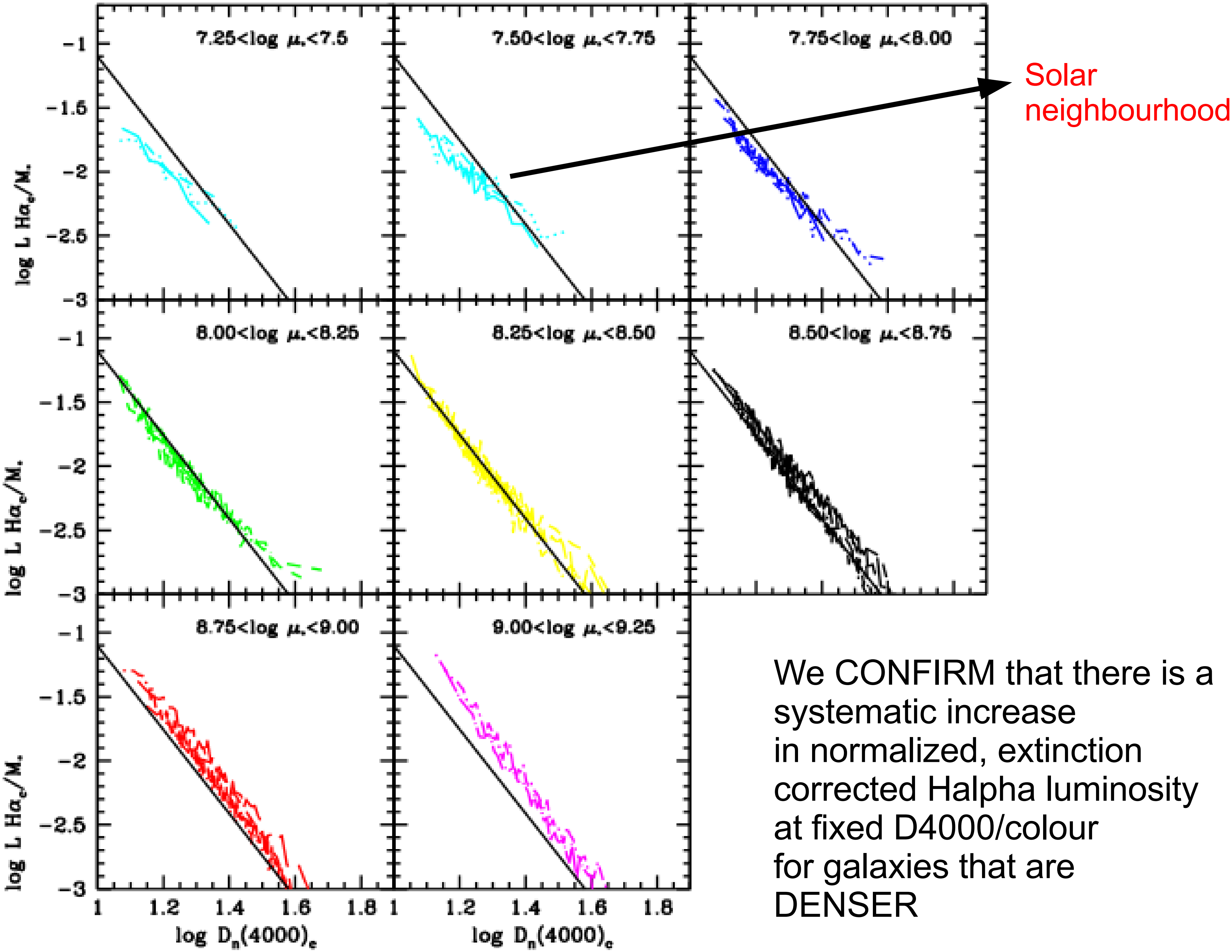
FIG. 10.—Synthetic profiles of a 2 Myr old instantaneous burst formed with a mass distributed between $M_{low} = 1\ M_\odot$ and $M_{up} = 80\ M_\odot$ at solar metallicity following a power-law IMF with index $\alpha = 2.35$ (*full line*), $\alpha = 1.0$ (*dashed line*), and $\alpha = 3.3$ (*dotted line*).

Sloan Digital Sky Survey

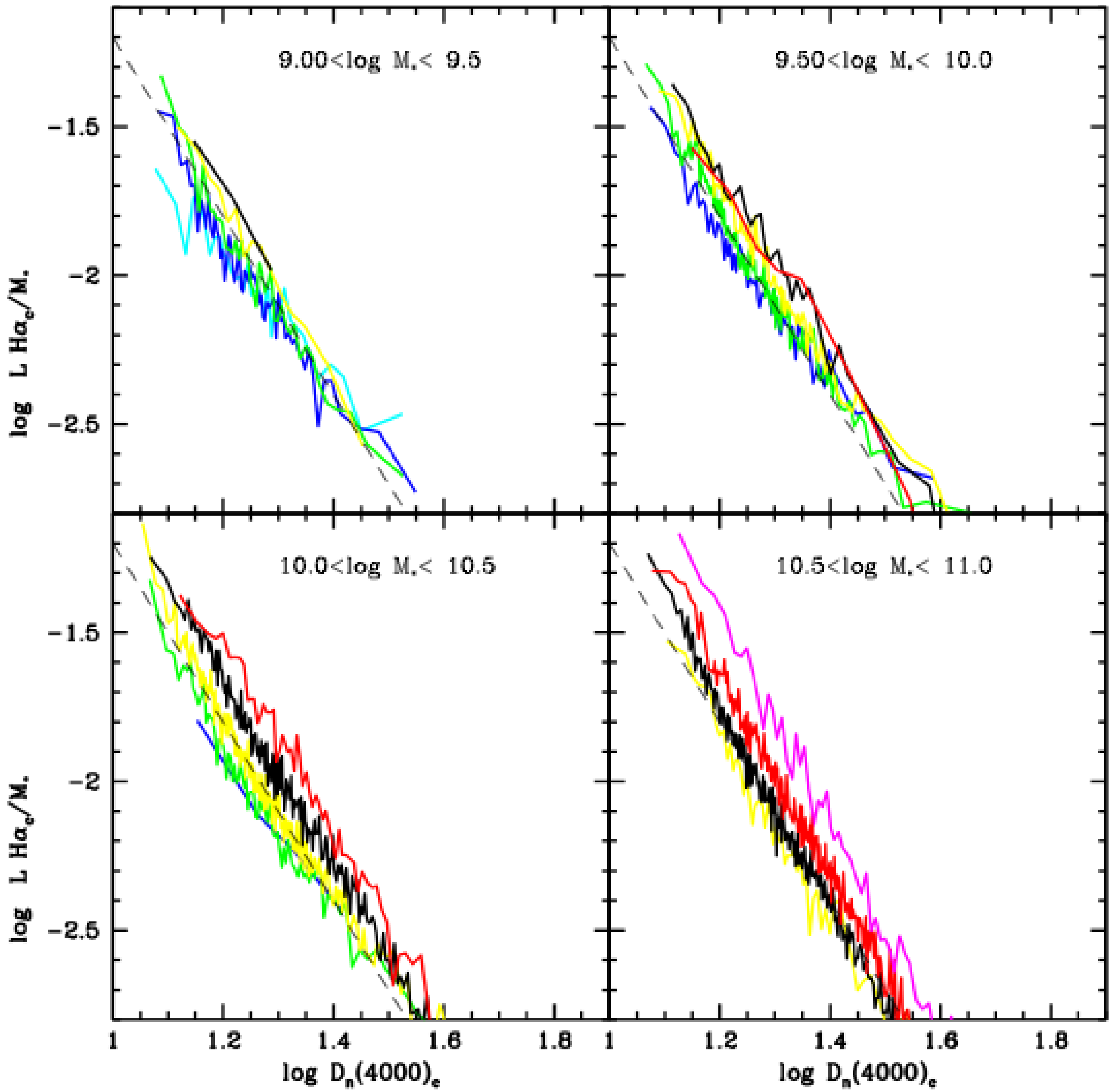




162,000 star-forming galaxies (AG
excluded)



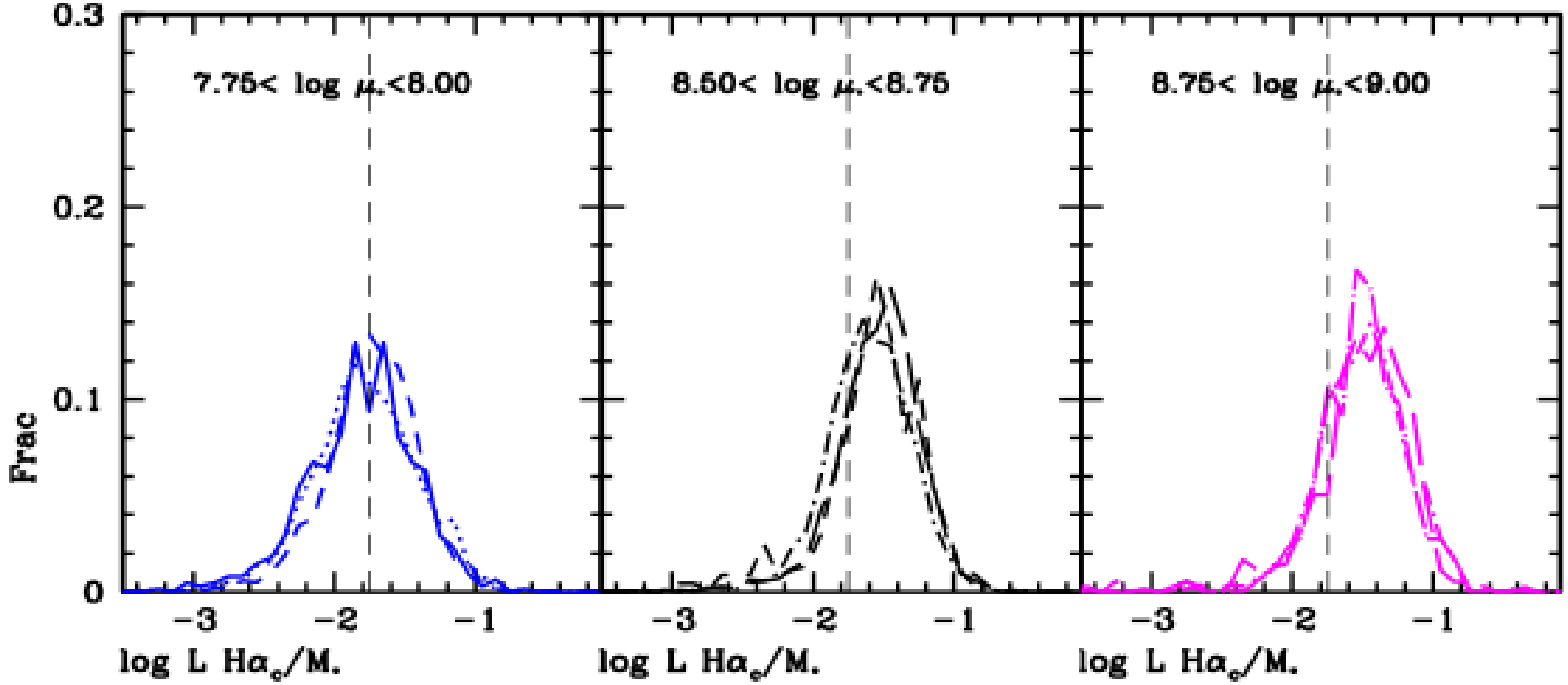
We CONFIRM that there is a systematic increase in normalized, extinction corrected Halpha luminosity at fixed D4000/colour for galaxies that are DENSER

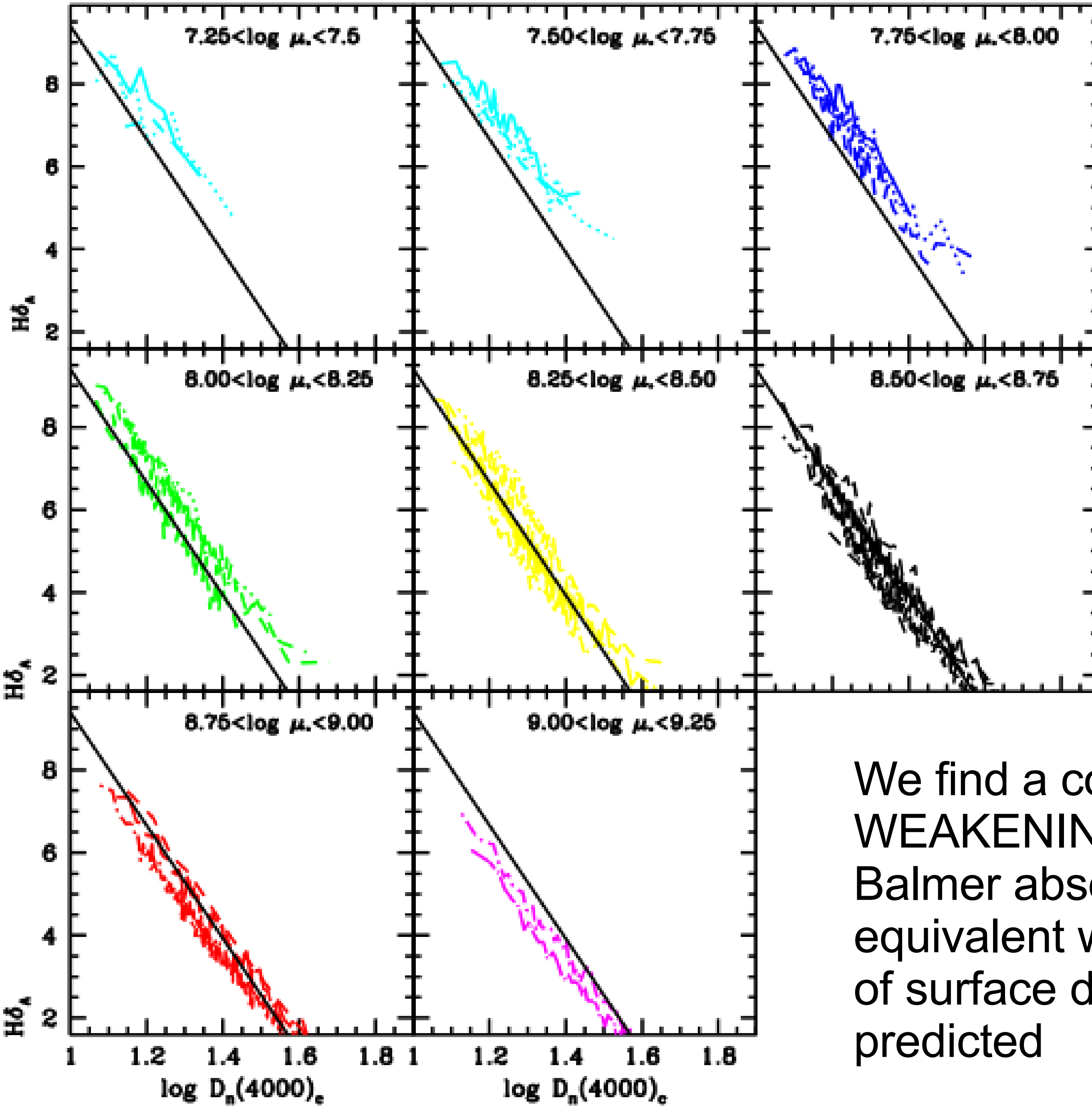


We ascertain that the parameter driving the effect is DENSITY and not mass.

(We hypothesize that GAS surface density is actually the key physical driver)

The DISTRIBUTION function of L(Halpha)/M* at fixed D4000 places strong constraints on scenarios that can explain this effects: it rules out changes in star formation history as the origin of the effect





We find a concomitant WEAKENING in the mean Balmer absorption line equivalent width as a function of surface density, as predicted

THINGS YOU MIGHT WORRY ABOUT AND HOW WE “PROVE” THEY ARE UNLIKELY TO MATTER

1) CORRECTIONS FOR DUST EXTINCTION

We find that dust corrections can influence the AMPLITUDE of our effect, but it cannot be the cause of it in the first place.

We find that the relation between EQW(Halpha) and D4000 is nearly invariant with density, but that the Balmer decement also increases strongly with density.

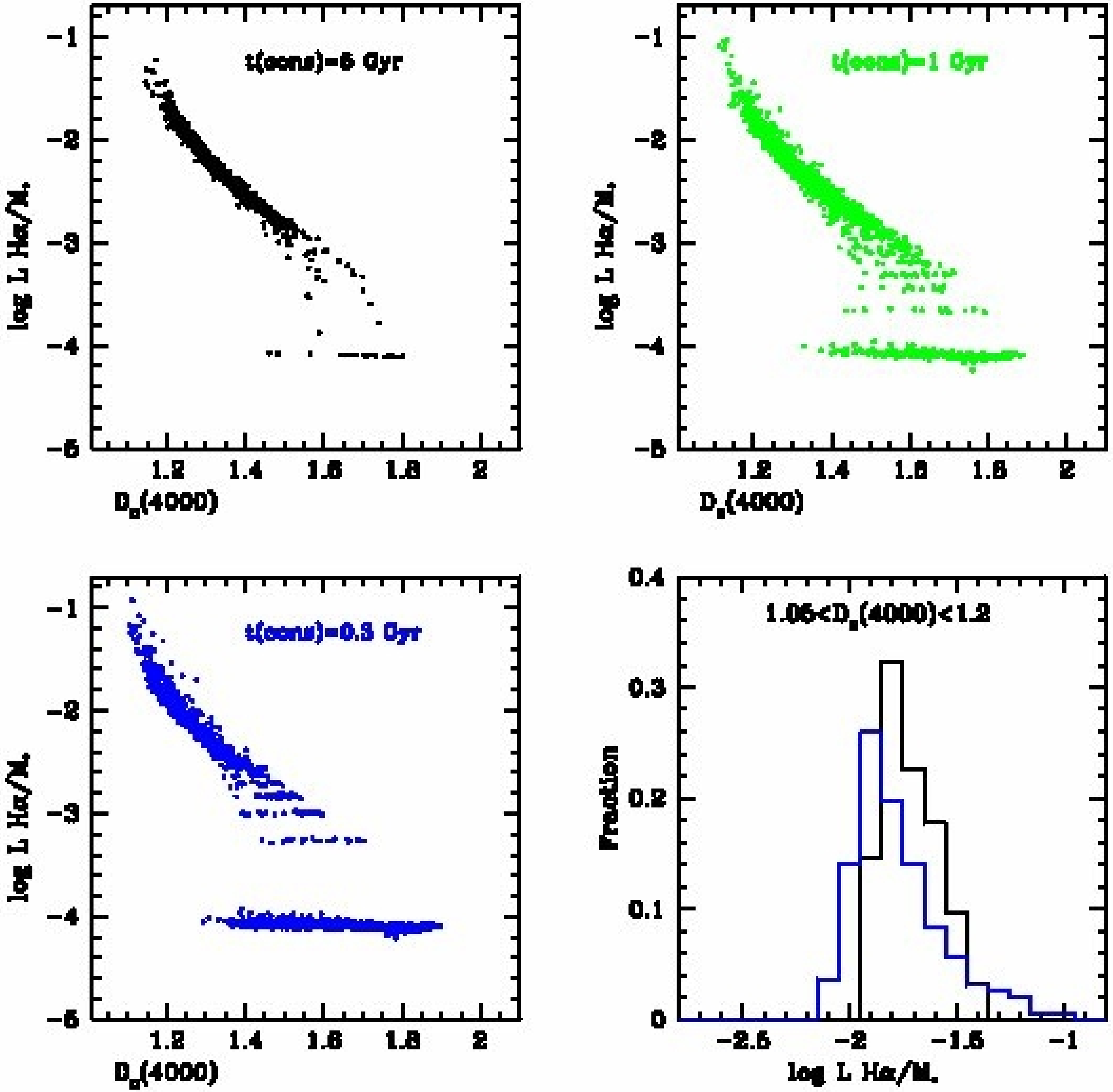
Hence, so long as emission lines suffer more extinction than the continuum, the effect must be there.

2) STAR FORMATION HISTORY

Changes in star formation history MUST CHANGE THE SHAPE of the distribution function of L(Halpha)/M_* at fixed D4000. Bursts produce a shift in the peak of the distribution towards lower values of L(Halpha)?M_* and a tail of high L(Halpha)/M* systems. This is not seen!

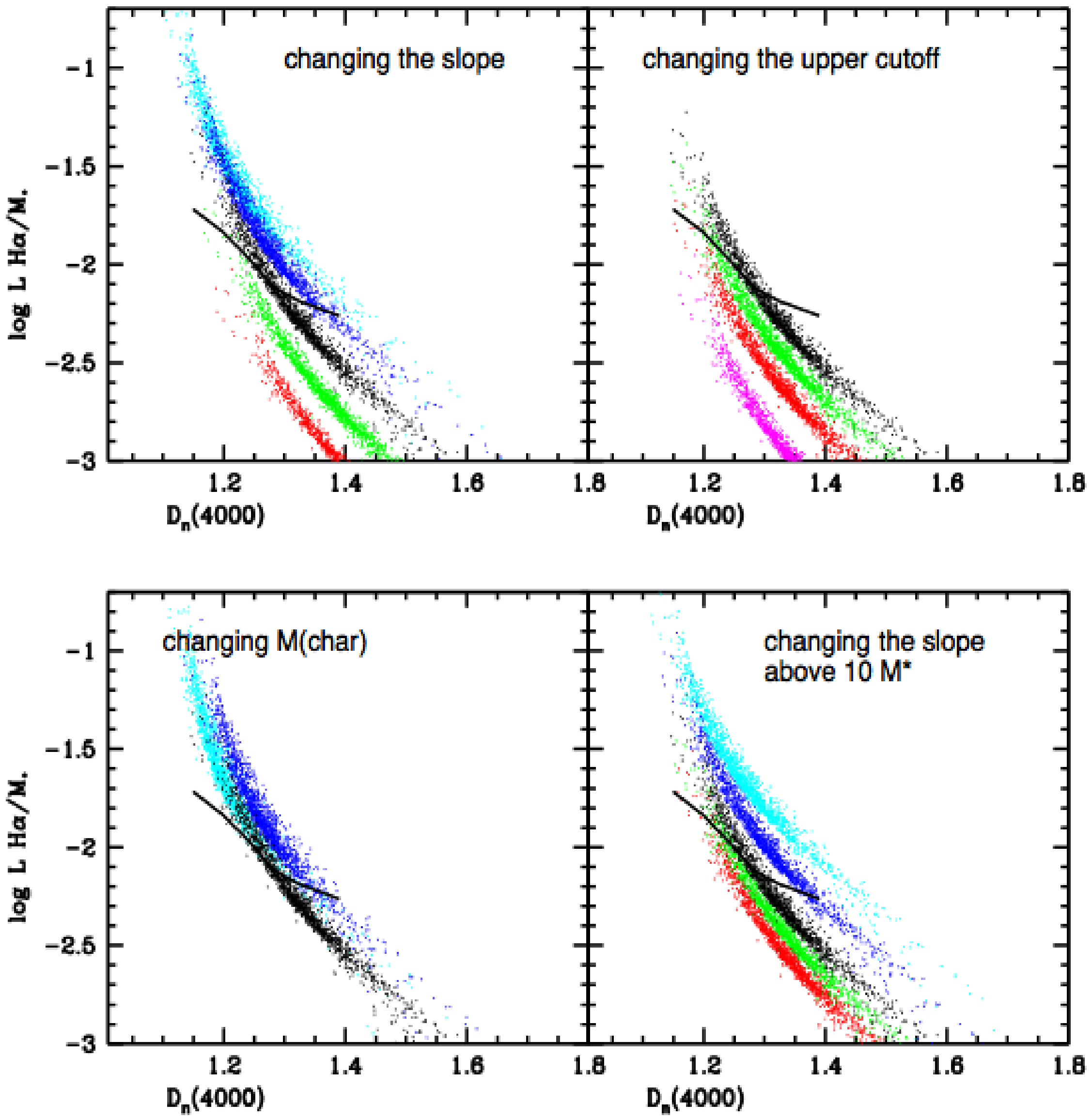
3) METALLICITY

We can use additional information from lines such as [NII] and [OII] to divide our galaxies into bins according to metallicity and prove that this is not the origin of the trends in the Balmer line equivalent widths

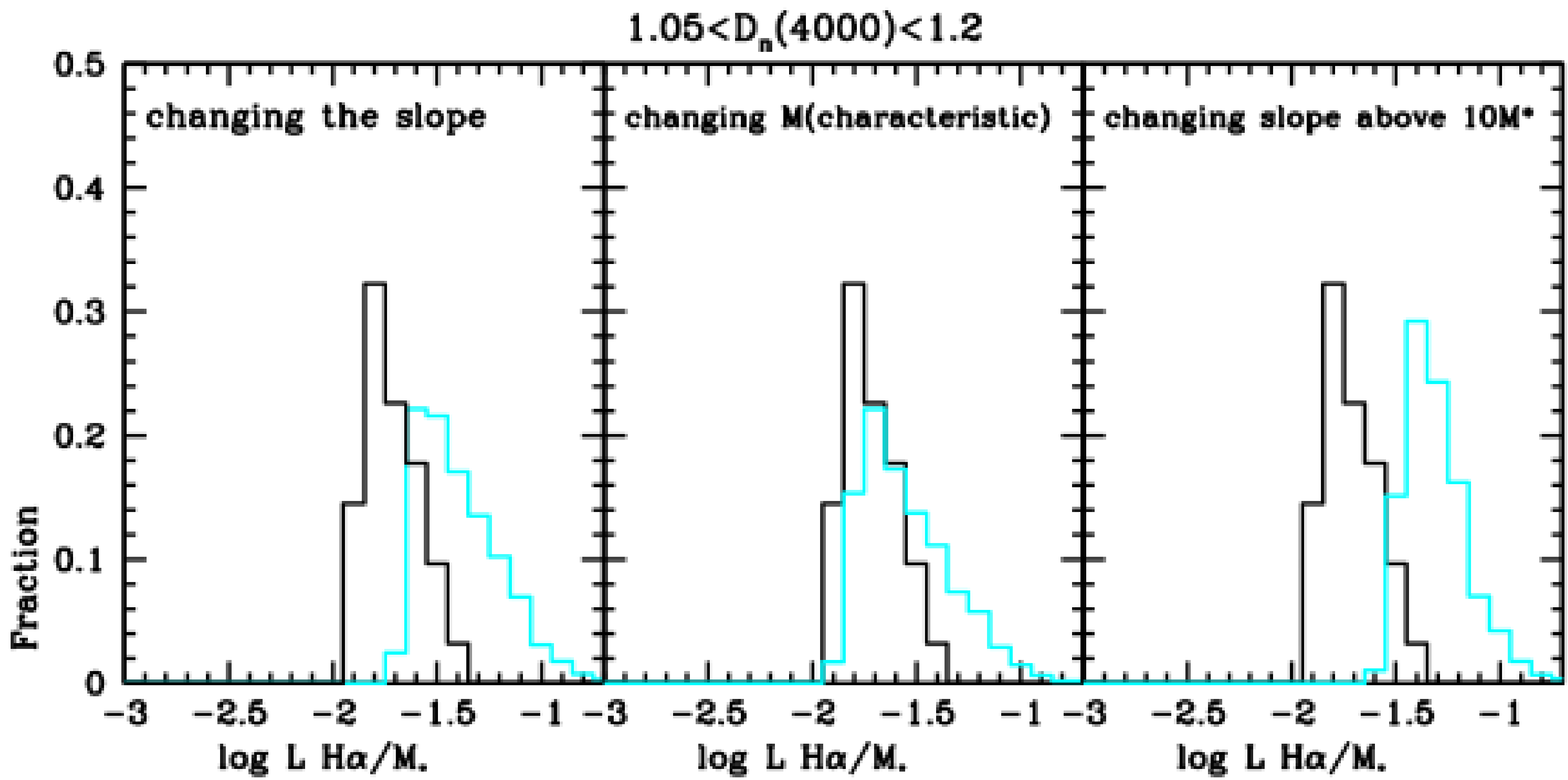


Why changes in star formation history don't work: the power of analysis of complete populations...

STELLAR POPULATION MODELLING: differential effects in emission lines and continuum are computed using PEGASE and PEGASE-HR, but the normalization at the canonical IMF is tied to BC03.



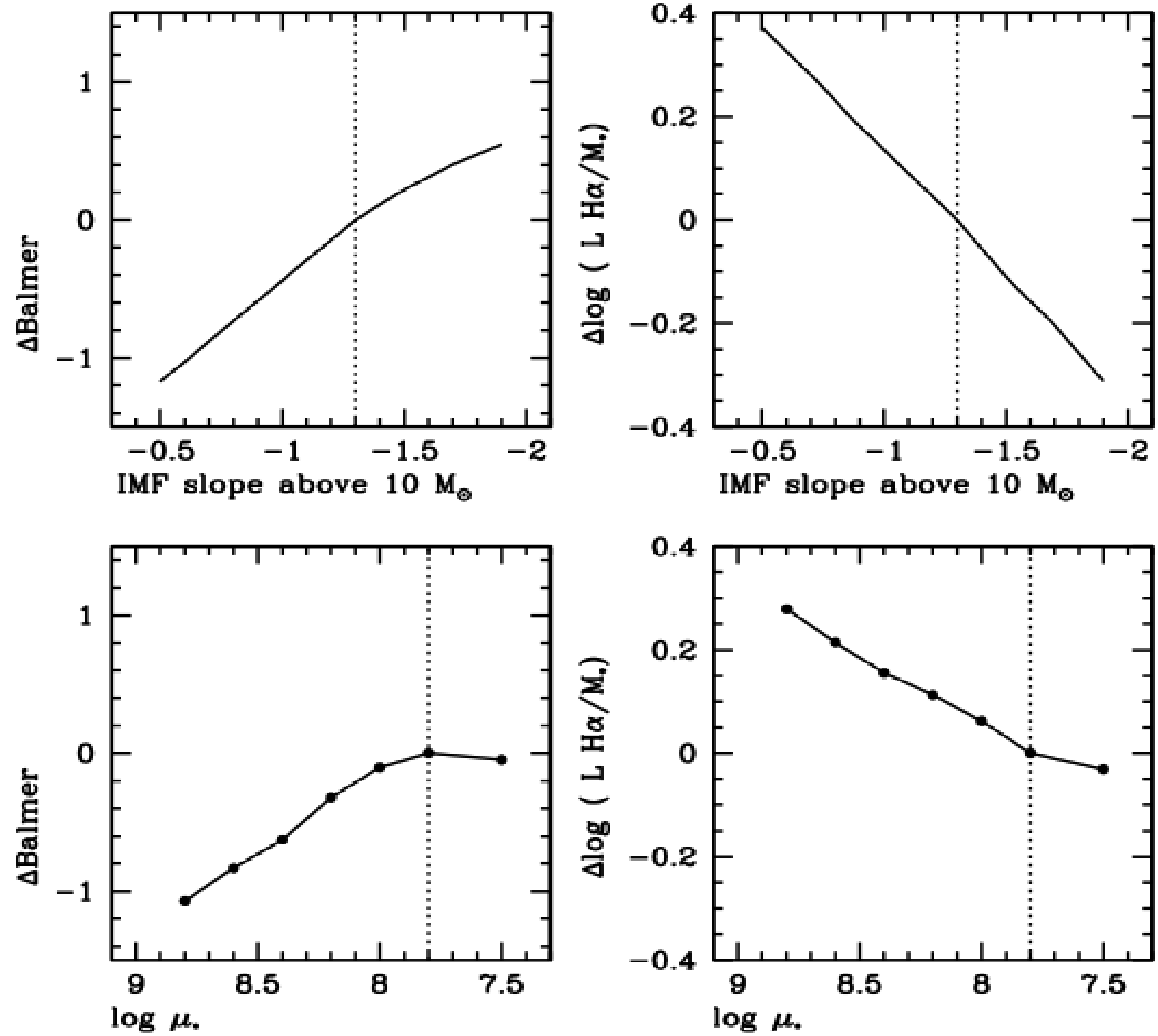
The distribution function of L(Halpha)/M* is again key in allowing us to distinguish between these possibilities. The only way we can get a simple shift , while keeping the shape invariant, is to change the relative number of stars above 10 M_sol. Changing the number of intermediate mass stars as proposed by Romeel Dave, will not give the right systematic trends to fit our data.

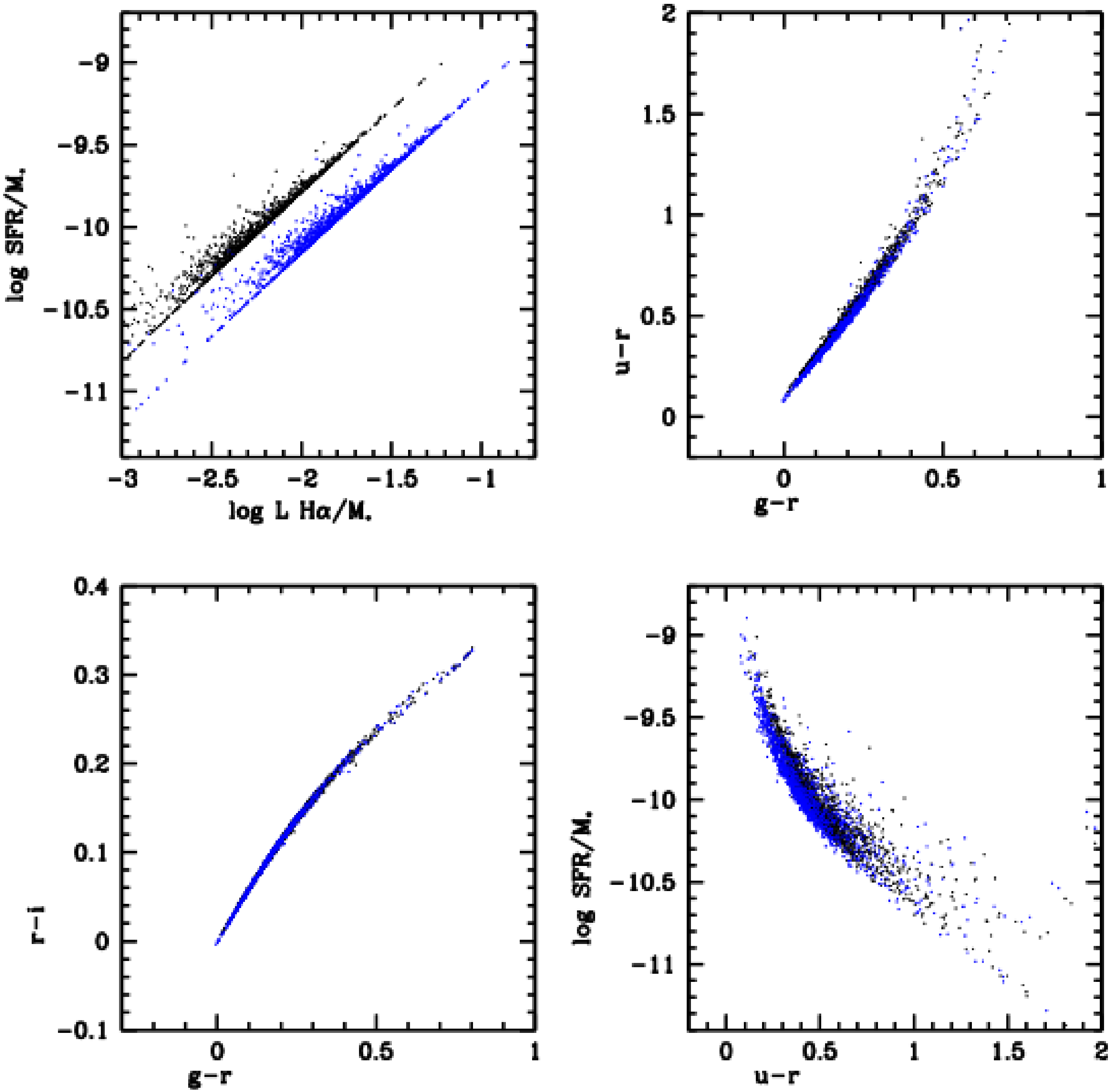


We then find a very nice consistency between the observed and predicted AMPLITUDES of the change in both L(Halpha)/M* and Balmer line strength

PEGASE predictions

OBSERVATIONS



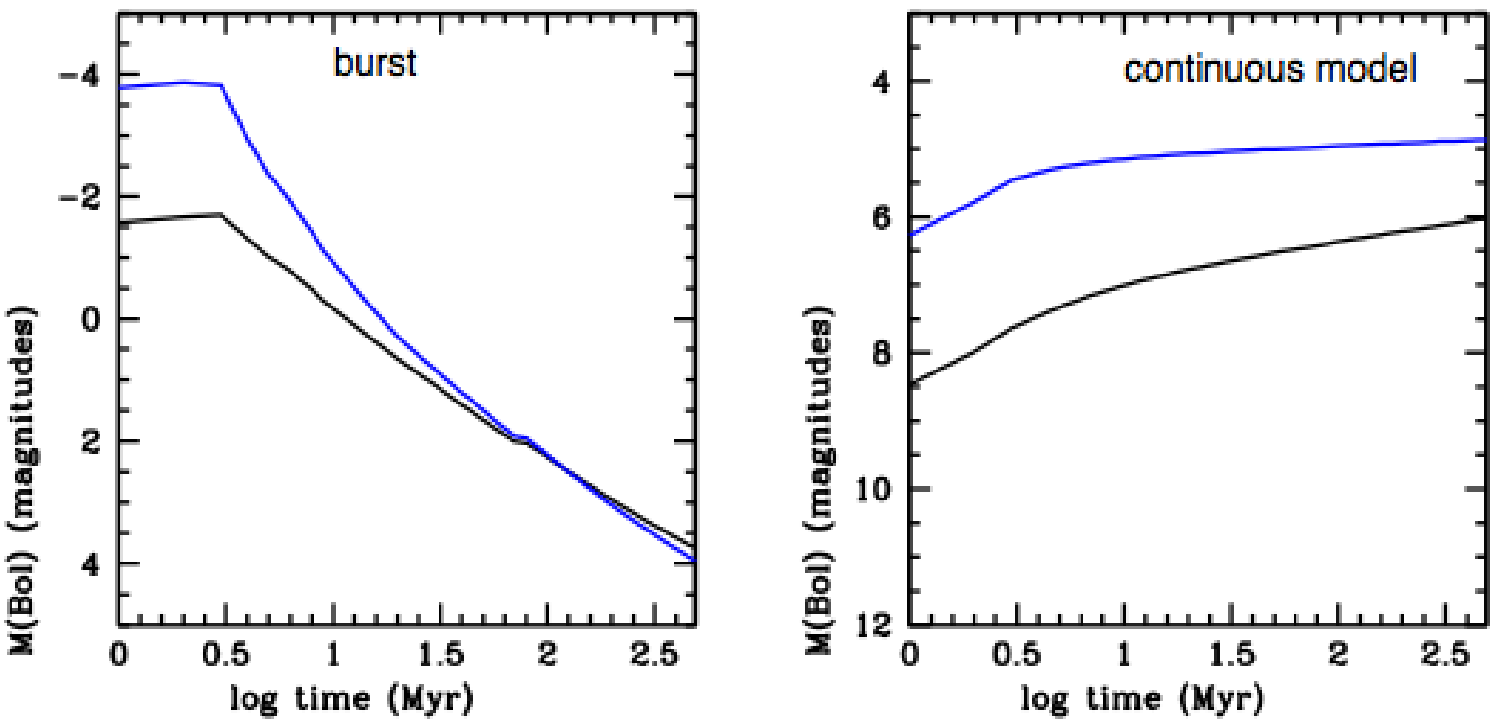


CONSEQUENCES:

Optical colour/colour diagrams remain essentially unchanged.

Prediction: there would be a discrepancy between SFR derived from emission lines and those derived from SED fitting techni

Predicted change in the Bolometric luminosity of starburst galaxies as a function of age, for a fixed star formation law



Star formation theorists may not be surprised by these results!

A Minimum Column Density of 1 g cm^-2 for Massive Star Formation

Mark R. Krumholz (Princeton University), Christopher F. McKee (UC Berkeley)

(Submitted on 2 Jan 2008)

Massive stars are very rare, but their extreme luminosities make them both the only type of young star we can observe in distant galaxies and the dominant energy sources in the universe today. They form rarely because efficient radiative cooling keeps most star-forming gas clouds close to isothermal as they collapse, and this favors fragmentation into stars <~1 Msun. Heating of a cloud by accreting low-mass stars within it can prevent fragmentation and allow formation of massive stars, but what properties a cloud must have to form massive stars, and thus where massive stars form in a galaxy, has not yet been determined. Here we show that only clouds with column densities >~ 1 g cm^-2 can avoid fragmentation and form massive stars. This threshold, and the environmental variation of the stellar initial mass function (IMF) that it implies, naturally explain the characteristic column densities of massive star clusters and the difference between the radial profiles of Halpha and UV emission in galactic disks. The existence of a threshold also implies that there should be detectable variations in the IMF with environment within the Galaxy and in the characteristic column densities of massive star clusters between galaxies, and that star formation rates in some galactic environments may have been systematically underestimated.

Comments: Accepted for publication in Nature; Nature manuscript style; main text: 14 pages, 3 figures; supplementary text: 8 pages, 1 figure

YET, the Guiding Principle in the Analysis of the High-Z Universe has been

IMF UNIVERSALITY HYPOTHESIS: the canonical IMF constitutes the parent distribution of all stellar populations.