Tidal Dwarf Galaxies: 
Their Present State and Future Evolution

U. Fritze - v. Alvensleben\textsuperscript{1} and P.-A. Duc\textsuperscript{2}

\textsuperscript{1}Universit"at-Sternwarte G"ottingen; \textsuperscript{2}ESO Garching

Evolutionary synthesis models for Tidal Dwarf Galaxies (TDGs) are presented that allow to have varying proportions of young stars formed in the merger-induced starburst and of stars from the merging spirals’ disks. Comparing model grids with observational data (see e.g. P.-A. Duc this conference for a review) we try to identify the present evolutionary state of TDGs. The influence of their specific metallicities as well as of the gaseous emission of actively star forming TDGs on their luminosity and colour evolution are studied.

1. Motivation and Method

P.-A. Duc (this volume) presents our present state of observational knowledge on Tidal Dwarf Galaxies (TDGs). The aim of the present investigation is to understand the past and present stages of evolution of TDGs in order to be able to restrict possible future evolutionary paths of these objects. While as early as 1956 Zwicky had already considered the possibility that self-gravitating objects in tidal tails might acquire dynamical independence and contribute to the population of dwarf galaxies, by today there are basically two alternative scenarii for the formation of TDGs:

- Stellar-dynamical models reveal local concentrations of stars along stellar tidal tails torn out from the disk of an interacting spiral (Barnes & Hernquist 1992). Gas, if present, may then fall into the potential well defined by disk stars.
- Hydro-dynamical models show local instabilities of gas along gaseous tidal tails that give rise to Super-Giant Molecular Clouds, which then may ignite a Burst of Star Formation (Elmegreen et al. 1993). Some stars, if present, might then fall into the potential defined by the gaseous component.

The method we use is chemical and spectrophotometric evolutionary synthesis, i.e. our modelling starts from a gas cloud, specifies two basic parameters – the Star Formation Rate in its time evolution ($\text{SFR}(t)$) and the IMF – and then follows the evolution of ISM abundances and of spectrophotometric properties of the stellar population including gaseous line and continuum emission for various metallicities. Our models, of course, have to rely on various pieces of input physics. Here, in particular, we use new Geneva stellar evolutionary tracks for various metallicities $Z = 10^{-3}$, $4 \cdot 10^{-3}$, $8 \cdot 10^{-3}$, $2 \cdot 10^{-2}$, $4 \cdot 10^{-2}$ (Schaller et al. 1992, Schaerer et al. 1993a, b, Charbonnel et al. 1993, 1996), Lyman continuum photons $N_{\text{Lyc}}$ from Schaerer & de Koter (1997), and emission line ratios of some 30 strong lines relative to H$\beta$ from photoionisation models (Stasińska 1984) for $Z_{\odot}$, and from HII region observations (Izotov et al. 1994) for $Z < Z_{\odot}$, and also include gaseous continuum emission.

Basic parameters for our modelling are the IMF, which we take from Scalo over the mass range from 0.1 \ldots 85 $M_{\odot}$ – and assume it to be identical for the interacting galaxies, the starburst, and the TDGs for simplicity – and the SFR $\Psi(t)$, which, for spiral galaxies we take to linearly depend on the gas-to-total mass ratio $\Psi \sim M_{\text{Gas}}/M_{\text{tot}}$ with characteristic times for SF $t_{\ast} = 3$, 10, 16 Gyr for Sb, Sc, Sd spirals. For these SF histories our models were shown to give agreement both with the chemical properties of spiral galaxies of various types as seen in HII region abundance...
observations as well as in the redshift evolution of Damped Lyα Absorber abundances (Fritze-v. A. et al. 1997) and with the spectral properties of nearby galaxy templates as well as with the photometric properties from galaxy redshift surveys (e.g. Lindner et al. 1996).

2. Metallicities of TDGs

From our modelling of spiral-spiral mergers – including the starbursts triggered by the interaction process in gas-rich systems – we predicted metallicities for stars and star clusters forming in the burst on the basis of the spirals galaxy ISM abundances. This metallicity prediction, of course, also applies to young stellar populations of TDGs. For gas-rich spirals of ages 8 – 12 Gyr, stars are expected to form with metallicities in the range \([\text{O}/\text{H}] = -0.7 \ldots 0.0\) (Fritze-v. Alvensleben & Gerhard 1994a,b). HII region abundances of TDGs fall well within this range: \([\text{O}/\text{H}] \text{(TDGs)} = -0.63 \ldots -0.33\) and are significantly higher, on average, than values derived from the L–Z relation for dwarfs (cf. Fig. 3, Duc et al., this volume).

3. Model Grid

Our models for nearby TDGs include two ingredients in various proportions in accordance with the two possible formation scenarios:

- a composite stellar population of age \(\sim 12\) Gyr from the progenitor disk (Sb, Sc, Sd) and
- a starburst of given strength and duration.

In the Barnes et al. formation scenario we expect a TDG to consist of a large contribution of disk stars, evolving passively since the tidal tail has been extracted from the spiral, and some a priori unknown contribution of young stars forming in a starburst from the gas trapped into the stellar potential. In the Elmegreen et al. scenario a dominant young burst population is expected. In our attempt to understand the presently available sample of TDGs, we calculate a grid of models covering various progenitor populations (Sb, Sc, Sd, all assumed to be between 8 and 12 Gyr old), various burst strengths and durations, and we also explore the influence of changes in the metallicities with respect to the predicted one.

The aim of the present investigation is to age-date the dominant stellar populations using the appropriate metallicity, to determine relative contributions from parent disk and young burst stars, to estimate the burst duration and to use all this information to predict the future luminosity and colour evolution. Gas reservoirs observed in HI on several TDGs are usually large enough to fuel SF at the present rate for Gyrs. Dynamical effects, as e.g. a possible fall-back of some TDGs onto the merger remnants (cf. Hibbard & Mihos 1995) or disruption by the parent galaxy, a group or a starburst-driven wind, are alltogether not included in our models.

4. First Results

4.1. Gaseous Emission

Fig. 1. shows the enormous importance of the gaseous emission for the broad band colours UBVIJHK during the active burst phase, confirming Krüger et al. ’s (1995) results obtained for starbursts in Blue Compact Dwarf galaxies. Decomposition of the total gaseous contribution in terms of line and continuum emission shows that while line emission is dominant in the optical, continuum emission dominates in the NIR.

The relative contributions of the young population formed in situ from a gas condensation in the tidal tail and the “old” (=composite in age and metallicity) population extracted from a spiral disk for our strong, intermediate, and weak burst models to the integrated light in B, V, and K bands, as well as to the total stellar mass \(S\) are displayed in Tab.1.
Figure 1: a) Relative contribution of gaseous emission to broad band colours UBVRIJHK 1 Myr after the onset of bursts of various strengths. b) Decomposition of the total gaseous emission contribution for a strong burst (Fig.1 a) into contributions from lines and continuum.

| Burst        | $L_{B}^{\text{young}}/L_{B}^{\text{old}}$ | $L_{V}^{\text{young}}/L_{V}^{\text{old}}$ | $L_{K}^{\text{young}}/L_{K}^{\text{old}}$ | $S_{\text{young}}/S_{\text{old}}$ |
|--------------|--------------------------------------|--------------------------------------|--------------------------------------|-------------------------------|
| Strong       | 26                                   | 20                                   | 2.7                                  | 0.4                           |
| Intermediate | 7                                    | 5                                    | 1.4                                  | 0.1                           |
| Weak         | 1.6                                  | 1.4                                  | 1.04                                 | 0.01                          |

Table 1: Relative contributions to luminosities in B,V, and K bands and to stellar mass $S$ of young burst and “old” disk stars.

It should be noted that while our starburst models give very good agreement with the standard formula for the transformation of $H_{\alpha}$ luminosity into SFR (Hunter & Gallagher 1986) for SFRs up to a few $M_{\odot}$yr$^{-1}$, they show that for SFRs $> 10$ $M_{\odot}$yr$^{-1}$ the standard SFR($L_{H_{\alpha}}$) strongly underestimates the true SFR (by a factor $\sim 3.6$ for SFRs $\gtrsim 50$ $M_{\odot}$yr$^{-1}$).

4.2. Colour Evolution

Fig. 2 gives the colour evolution through and after bursts of various strengths on top of a 12 Gyr Sc population (u.g.). Model curves are for [Fe/H] = −0.4. Starting from the colour of the u.g. at 12 Gyr, model galaxies evolve clockwise along the curves. Evolution to the bluest point takes $\sim 7$ Myr, from there back to the u.g. colours takes 16 to 30 Myr, and from there to the end of the graph $\sim 2.6$ Gyr. Pure burst models without any underlying population from the spiral disk would start in the upper left corner of the diagrams and evolve toward the lower left on the same passive evolutionary reddening path as the strong burst models. TDGs from Duc’s compilation are plotted twice: $\Diamond$ : corrected for the total extinction $A_{B}$ as derived from the Balmer decrement, $\Diamond$ : corrected for Galactic extinction only. While the extinction from the Balmer decrement might somehow overestimate the extinction on integrated colours, the Galactic extinction gives a lower limit. Typical errors for the colours are of order $\sim 0.2$ mag.

It is seen from Figs 2. that the bulk of the TDGs from Duc’s sample seem to feature quite strong starbursts on top of a composite stellar population of disk stars. Due to the uncertainties in the reddening correction it is not clear, though, if within the present sample of TDGs, there really are pure bursts without underlying component or purely “old”, passively evolving stellar subsystems from spiral disks.
4.3. Luminosity Evolution
The stronger the light contribution of the young burst star population, the stronger the fading. For TDGs with a strong burst population the fading in B within $\sim 1$ Gyr may easily amount to 2 – 3 mag, slightly depending on $[\text{Fe/H}]$, while in K the brightening as well as the fading during the 1st Gyr even of a strong burst hardly exceed 1 mag. A correct estimate of the “old” star population is crucial for a reliable fading prediction.

4.4. A105S: a first example
Emission line spectroscopy gives a metallicity $[\text{O/H}] = -0.6$, colours from B through K indicate a strong burst of short duration $t_\ast \sim 10^6$ yr and a burst age of $(2-6) \cdot 10^7$ yr. The stellar mass we estimate using the $M/L_K$ at this age from our model is $\sim 4 \cdot 10^8 \, M_\odot$. Together with the observed $M(\text{HI}) \sim 5 \cdot 10^8 \, M_\odot$ it reasonably agrees with the dynamical mass $M_{\text{dyn}} \sim 1 \cdot 10^9 \, M_\odot$ obtained from the rotation curve. While the light contribution from the “old” disk star population accounts for 44 % of the total $L_K$ it only make up 4 % of the present $L_B$. The mass of the old population derived from $L_K$ is $\sim 3 \cdot 10^8 \, M_\odot$. The stellar mass of A105S thus is by far dominated by the ”old” population. This has important implications for both the dynamical and the photometric evolution of this TDG.

5. Outlook
Next steps will obviously be to study burst strengths and fading for a sample of TDGs in order to define the range of burst strengths and durations realised in TDGs, in particular to assess the question if there are purely young starburst TDGs and purely “old” passively evolving disk star condensations (→ Diploma thesis P. Weilbacher). Only then can our speculation about a possible contribution of TDGs to the Faint Blue Galaxy excess be put on quantitative grounds.

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