The star formation law in Tidal Dwarf Galaxies

U. Lisenfeld[1], P.-A. Duc[2], J. Braine[3], E. Brinks[4], M. Boquien[5], F. Bournaud[2]

(1) Universidad de Granada, Spain (2) CEA-Saclay, France (3) Observatoire de Bordeaux, France (4) University of Hertfordshire, UK (5) University of Cambridge, UK

Summary

Tidal Dwarf Galaxies (TDGs), formed from recycled gas in galaxy interactions, have in general similar properties as ordinary dwarf galaxies. One important difference is their **higher (close to solar) metallicity** since they are made from recyled gas. This property makes **CO a good tracer for the molecular gas content**. This allows us to **directly study the relation between the star formation (SF) and the molecular gas** in this special environment which is characterized by a lack of spiral density waves and the presence of tidal forces**.** We can summarize our results from a sample of 14 TDGs with single dish and interferometric CO data:

We generally find a **close relation between the star formation rate (SFR) per area and the molecular gas mass surface density** (the Kennicutt-Schmidt law) consistent with that found in spiral galaxies. There are, however, **two noteable exceptions** from this relation:

- We find in some cases abundant quantities of molecular gas which are not associated to any star formation. The line width of this component is generally broader than that of the star-forming molecular gas.
- In one object (VCC 2062) we find a clear deviations from the SF law with a considerably lower star formation efficieny (SFE=SFR/M(H_2)). This could either be due to a genuinely local low star formation efficiency or due the presence of close-by molecular gas which is not associated to the star formation.

Molecular gas in TDGs

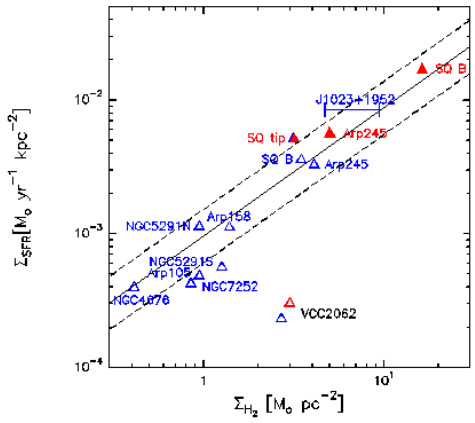
We have observed the CO(1-0) emission of a sample of 14 TDG, both with single dish (IRAM 30m telescope) and with interferometric instruments (IRAM Plateau de Bure/OVRO). The general conclusions from these spectra (see examples) are:

- There is generally good spatial and kinematical agreement between the CO and the HI spectra.
- CO is found where SF takes place.
- CO is sometimes found abundantly outside SF region. The line-width of the molecular gas outside SF regions is usually broader.

The SF law in TDGs

Below we show the surface density of the molecular gas vs the SFR per area for our sample of TDGs. The SFR was estimated mostly from Hα, but also from UV and 8 μm. We compare this relation to the SF law found for spiral galaxies. We conclude:

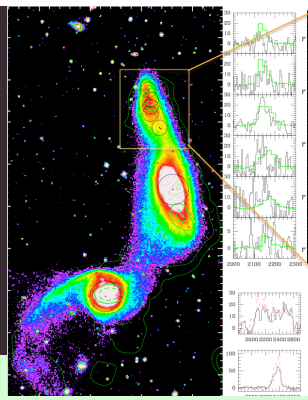
- Most objects follow the general SF law for spiral galaxies.
- There is one clear outlier (VCC 2062). Its low SFR is a robust result since different tracers (UV, Hα and 8mu) give consistent results. This can either be due to genuinely inefficient star formation (e.g. due to diffuse molecular gas without dense cores traced by CO) or due to the presence of close-by molecular gas which is not related to the observed SF.



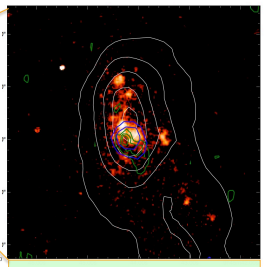
The SF law derived from all the available CO data. **Red data points are from interferometric data and blue data points from single dish data.** The full line shows the (linear) SF law derived from Bigiel (2008, 2011) for spiral galaxies, corresponding to a star formation efficiency log(SFR/M(H_2)) = -9.2 , and the dashed line the standard deviation of 0.23 dex.

Example 1: Arp 245N, a "classical" TDG

Optical true colour image (BVR bands), showing the system (from Duc+ 2000) .



Optical B-band image. Ellipses show the position where CO spectra where taken with the IRAM 30m telescope. At the right the CO spectra (green) are overlaid with the HI spectra at the same positions (from Braine+2001).



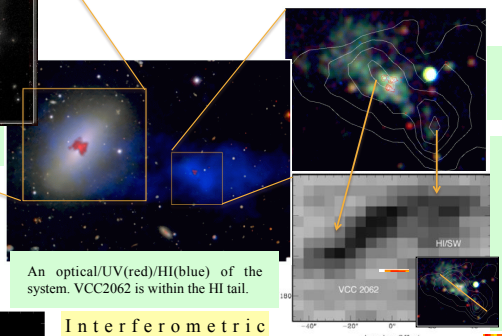
An overlay of SF and gas tracers in Arp 245N (Color image: Hα, magenta contours: 24μm, green contours: CO from OVRO, white contours: HI.)

Arp 245 is an interacting system of two galaxies with two tidal tails. At the end of the northern tidal tail a TDG has formed. Single dish observations show that CO is distributed along the entire object whereas OVRO interferometric observation show molecular clouds that are directly coinciding with the SF region.

Example 2: VCC 2062, an old TDG in the Virgo cluster

VCC 2062 is a dwarf galaxy close to NGC4694, a perturbed early-type galaxy, connected to it by a huge HI tail. An ample data set allows us to study the SF and molecular gas in spectacular detail in this object.

Optical image of NGC 4695,

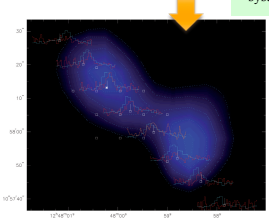


An optical/UV(red)/HI(blue) of the system. VCC2062 is within the HI tail.

Optical image of VCC 2062, with contours of HI (white) and Hα (red).

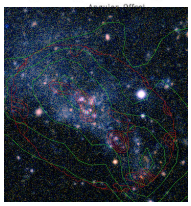
The position-velocity diagram of HI from a NE-to-SW cut (see inlet for its direction) shows that in the SF region the lines are narrow and have a velocity gradient, whereas the region without SF has broad lines and no gradient.

In VCC 2062 and the associated HI cloud, abundant molecular gas has been found.

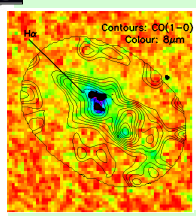


CO (observed with the IRAM 30m telescope) and HI spectra within the HI cloud.

Interferometric observations of CO(1-0) (observed with IRAM Plateau de Bure) show a close correspondance between SF and CO. However, the SFE is exceptionally low.



Optical image overlaid with HI (green) and CO (red) contours.



8 μm image overlaid with CO (black) and Hα (grey, filled contours).