Tidal Dwarf Galaxies

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Abstract

In collisions of massive galaxies a fraction of the material from the outer parts of the merging partners can be torn out to distances of up to 100kpc and form extended structures known as tidal arms. Observations and simulations now give evidence that stars and gas in the end of tidal tails may recondense to form a new generation of small star-forming galaxies, the so-called Tidal Dwarf Galaxies (TDGs).

1 Introduction

Simulations as well as observations of colliding massive galaxies have shown that tidal forces can pull out a vast amount of matter (up to one third of the mass of the pre-encounter galaxies (Duc et al., 1999)) into the intergalactic space. Already Zwicky (1956) proposed the idea that this ejection of stars and gas into the intergalactic space may lead to the formation of star clusters and even star forming galaxies.

Although tidal tails can contain a big number of star forming knots, the knots typically regarded as TDGs are the knots at the tips of the tidal tails. Those conglomerations of matter have the highest probability to survive as gravitational entities after leaving the parental galaxies.

2 Formation of tidal tails

Tidal tails can be divided into two main categories: The tidal tails formed in disk-disk collisions typically are formed out of expelled gas and stars, whereas tidal tails formed in interactions involving early type galaxies will not contain a significant amount of stars since it’s difficult to form stellar tails
due to the pressure supported nature of the stellar dynamics of ellipticals. In the second case the tidal tails will be pure HI tails (Duc et al., 1999).

Typical tidal tails can reach out about 100kpc into the intergalactic medium and have a typical width of 3kpc. Typical collision ages of the interacting galaxies are about $1 - 5 \times 10^8$ yrs.

3 Formation of TDGs

The formation of TDGs can be explained by two models (or the combination of them): 1) A local dynamical instability in the old stellar population of tidal dwarfs probably caused by environmental effects like ram pressure leads to the accretion of gas. This is only happening of course if there is already a stellar component in the tidal arm. 2) The collapse of a supermassive cloud triggers star formation (Duc et al., 1999).

4 TDGs as galaxies

It is now time to try to understand the definition of galaxies. Wikipedia states: A galaxy is a huge gravitationally bound system of stars, interstellar gas and dust, plasma, and (possibly) unseen dark matter. So let’s see which of these compounds have been found so far:

4.1 Gas

The atomic gas content of TDGs stems from the progenitors and can have a value of up to $6 \times 10^9 M_\odot$ (Duc et al., 1999).

Molecular gas of up to a few $10^8 M_\odot$ has been observed by Braine et al. (2001) in 8 TDGs via the detection of CO. Since the CO emission coincides both spatially and kinematically with the HI emission, the conclusion is drawn, that TDGs are able to convert their neutral hydrogen into molecular gas which process takes place on dust grains. There might be a trend that more evolved TDGs have greater molecular gas masses. CO is believed to be a good tracer for molecular hydrogen due to the high metallicity in TDGs since the $N(H_2)/I_{CO}$ conversion factor does not seem to be radically different in TDGs and in spirals. Another effect of the high metallicity in tidal dwarfs is that the presence of metals facilitates the cooling of the gas and the formation of $H_2$ molecules.
Warm molecular gas has been detected by Higdon et al., 2006 in the TDGs NGC5291 N and S. They derive a mass of the warm molecular hydrogen being around $10^5 M_{\odot}$ having a temperature of around 400K.

Besides this atomic gas, there are also HII regions ionized by massive OB stars younger than 10Myrs indicating that there is massive star formation in progress in TDGs (Duc et al., 1999).

4.2 Dust

Although there has to be dust in TDGs due to the formation of molecular gas and stars, I have not seen direct studies about its amount and nature. Braine et al., 1999 claim, that the dust in TDGs originates from the parent galaxies. 1.2mm observations (unpublished and carried out by me :-) have only shown upper limits of dust. But Higdon et al. (2006) have recently shown that there is PAH emission in the NGC 5291 N and S TDGs, indicating dust emission in TDGs with a temperature of around 140K.

4.3 Stars

TDGs may have (depending on their origin meaning whether the parental galaxies were spirals or ellipticals) two stellar components. An old stellar component is the remain of the stars pulled out from the parental galaxies, and a young component being formed after the formation of the TDG out of the gaseous material. The equivalent width of the optical Balmer lines (Duc et al., 1999) indicates that the current star-forming episode is younger than 10 Myrs. The existing HI reservoirs can keep up star formation for several Gyrs. Star formation occurs at rates which might reach $0.1 M_{\odot} yr^{-1}$. Due to the huge HI reservoir of TDGs the relative importance of the (possibly existing) older stellar population will decrease with time as star formation proceeds (Duc et al., 2001).

4.4 Metallicity

Tidal dwarf galaxies consist of recycled matter. This means that the matter is not comparable to the matter of other known dwarf galaxies since it was already processed in the parental galaxies up to the point the TDGs were formed. Due to this the metallicity measured through the oxygen abundance is very high, $Z/3$ on average, which is the typical value of the outer regions of spiral galaxies. This states a difference to other dwarf galaxies (where
the metallicities are typically much lower) and allows a distinction between TDGs and normal dwarf galaxies (Duc et al., 1999).

4.5 Dynamics

Due to the rotational indications of HI clouds associated with TDGs as well as strong velocity gradients of the ionized gas, Duc et al. (1999) assume that TDGs may be gravitationally bound and dynamically independent of the parental galaxies.

Braine et al. (2001) have also made studies of the dynamics using the CO line width. CO is likely the better tracer of the dynamics of TDGs since some fraction of the HI near the TDGs may be part of the tidal tail and not bound to the TDG as CO presumably is (since it is formed in the TDG itself and not pulled out of the progenitor galaxy), and also because the CO is likely to be roughly as extended as the mass distribution of the tidal dwarf.

Bournaud et al. (2004) made observations of Hα and numerical simulations to understand the large scale kinematics (streaming motions along the tidal tails) and the small scale kinematics (internal dynamics of giant HII regions). The internal dynamics show for one TDG example (NGC 5291North) that it is self-gravitating and rotating, while non-circular motions are also observed.

4.6 Dark matter

Braine et al. (2001) argue, that it is justified to calculate a virial mass from the line widths of the CO line, and they derive from that that these TDGs are kinematically distinct from the parent galaxies. With the help of the CO line widths the dynamical mass of tidal dwarfs is then computed (they point out that the uncertainties are fairly large due to the unknown geometry and relaxation of the objects) and compared to the visible masses (HI + H₂ + stellar component). They state, that no dark matter is required to explain the observed CO line widths. They conclude, that TDGs are the only dark matter free galaxies identified so far, that TDGs are not representative of the population of dwarf galaxies with measured rotation curves as these are quite dark matter rich, and that dark matter must be found in the large size haloes of spiral galaxies.

Indeed, Bournaud et al. (2003) have made numerical simulations in order to study the extent of dark matter halos around massive spiral galaxies. In order to reproduce the observations of TDGs in interacting galaxies they...
needed to design the DM halos being up to 10 times the radius of the stellar disk. This puts a lower limit onto DM halo sizes of disk galaxies.

5 Evolution and survival of TDGs

5.1 Evolutionary stages of TDGs

TDGs can be arranged in a morphological sequence which follows their degree of detachment from the tidal tail and the compactness of the object (Braine et al., 2001). The conversion of HI into H$_2$ during the contraction suggests the mass ratio of HI to H$_2$ as another tracer of the evolutionary state.

5.2 Survival of TDGs

Due to the very hostile environment TDGs are in, it is possible that tidal dwarfs fall back onto their parental galaxies in timescales of around 1Gyr, get tidally disrupted by the gravitational forces of the parents or blow their gas content out into the IGM due to starbursts (this possibility is excluded due to observational evidence by Braine et al., 2001). So only the most massive TDGs that are the furthest away from the progenitors have a chance to survive in timescales of Gyrs (Duc et al., 1999).

The TDGs that are formed at radii larger than 50kpc are still observed after 2 Gyrs. One third of them remain on orbits that are almost circular and hence appear as satellite galaxies. Therefore such TDGs can not be considered as transient objects. Old TDGs should exist and be observed (Bournaud et al., 2003).

These surviving TDGs could be today’s members of Hickson compact groups or galaxy clusters (Duc et al., 1999). In order to identify TDGs among dwarf galaxies, one uses the special properties of TDGs like the metallicity, the dark matter content, the stellar population (Duc et al., 2001). Together with the metallicity difference comes a difference in the amount of CO detected in the galaxies which is roughly a factor 100 higher than for other dwarf galaxies of similar luminosity and star formation rate (Braine et al., 2001).
6 Projection effects

Bournaud et al. (2004) made (as mentioned before) observational and numerical research concerning the large-scale velocity gradients in tidal tails due to streaming motions along the tails. Their result for some of the sources (Arp105N, IC1182) was, that the accumulations of matter in the tips of the tidal tails were projection effects due to an alignment of the tidal tail with the line-of-sight. So careful studies of the data and computer simulations are very important in order to avoid wrong TDG identifications.

References

[9] Zwicky, F. 1956, Naturwissenschaften, 29, 344