Tidal Dwarf Galaxies: disc formation at z=0

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What is a Tidal Dwarf Galaxy (TDG)?

Different types of objects are formed during interactions/mergers:

- **Intergalactic HII regions**
  - Mendes de Oliveira et al., 2004

- **Intergalactic shocks**
  - Appleton et al., 2006

- **(Super) Star Clusters**
  - Gallagher et al., 2001

- **Tidal Dwarf Galaxies**
  - Lisenfeld et al., 2002, 2004
  - Stephan's Quintet (Duc+2006)

**TDG candidates** = Massive condensations of gas & young stars ($\sim 10^8$-$10^9 M_{\odot}$)
Most massive TDGs can survive:
How many dwarfs have tidal origin?
(Bournaud & Duc 2006; Ploeckinger+2014, 2015)

Simulated TDGs are rotation supported and devoid of non-baryonic dark matter!
(Barnes & Hernquist 1992; Elmegreen+1993; Duc+2004; Bournaud & Duc 2006; Wetzelein+2007; Bournaud+2008)
Prediction: TDGs should be free of DM!

- Tides have different effects on the dynamically-cold disc w.r.t. the dynamically-hot DM halo (e.g. Barnes & Hernquist 1992):
  - Disc --> tails, bridges, and eventually TDGs
  - Halo --> too dynamically-hot to form tails
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- TDGs have shallow potential wells with $V_{\text{rot}} \sim 50 \text{ km/s}$:
  They cannot accrete DM particles with $V_{\text{disp}} \sim 200 \text{ km/s}$!
Previous kinematic studies on TDGs

Braine+2001: No evidence of DM!

Bournaud+2007: Evidence of DM!

Rotation velocities from CO line-widths (TDGs unresolved)

Rotation velocities from HI interferometry (TDGs barely resolved)

MISSING MASS IN TDGS?

CO-dark molecules?

PV diagram

Visible Mass ($M_{\odot}$)

| $R \Delta V^2 / G M_\odot$ | $\log_{10}$ | $\log_{10}$ |
|---------------------------|-------------|-------------|
| N7252W                    | 10^9        | 10^9        |
| N4876N                    | 10^9        | 10^9        |
| N5291N                    | 10^8        | 10^8        |
| N5291S                    | 10^8        | 10^8        |
| A245N                     | 10^7        | 10^7        |
| A108S                     | 10^7        | 10^7        |
| N7319                     | 10^7        | 10^7        |
| N4038S                    | 10^8        | 10^8        |
Lelli+2015: sample of 6 TDGs

Head-on Collision

NGC 5291N
NGC 5291
"The Seashell"
NGC 5291S
NGC 5291SW

Post-Merger ETG

NGC 4694
VCC 2062

Late-stage Merger

NGC 7252
NGC 7252SE
NGC 7252NW

Blue = HI (VLA)
Pink = FUV (GALEX)

Yellow = Tidal Dwarf Galaxies
Lelli, Duc, Brinks et al. 2015, A&A, submitted

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Requirements to be a bona-fide TDG:

1) High metallicities

2) Kinematically distinct components

Young TDGs are forming out of pre-enriched material ejected from massive progenitors!

TDGs are associated with steep HI velocity gradients: rotation in a local potential well? Gravitationally bound?
Rotating disc models for TDGs

Lelli+2015, submitted:
- High-Res. VLA data
- 3D kinematical model

\[ V_{\text{rot}} \sim 20 \text{ km/s} \]
\[ R_{\text{HI}} \sim 8 \text{ kpc} \]
\[ \frac{M_{\text{gas}}}{M_*} \sim 8!! \]

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Observational facts on TDGs:

- Condensations of HI, molecules, and young stars:
  Masses, sizes, and SFRs similar to typical dwarfs

- TDGs deviate from the $M_\star-Z$ relation:
  They are *not* pre-existing dwarfs, but new-born objects

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  Consistent with regularly rotating discs (Lelli+2015)
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**PUZZLING ISSUE:** $t_{\text{orb}} > t_{\text{merg}}$ (or TDG "age")

These HI discs didn't have time to complete a full revolution!

Are they in dynamical equilibrium? Can we estimate $M_{\text{dyn}}$?
IF the discs are in dynamical equilibrium...

No Dark Matter! (as expected from simulations)

Deviation from the baryonic TF relation!

\[ \frac{M_{\text{dyn}}}{M_{\text{bar}}} \sim 1! \]

The high values reported by Bournaud et al. (2007) are *not* confirmed.

Caution: the shape of the rotation curve is uncertain. We may not be tracing \( V_{\text{flat}} \)
Conclusions:

- TDGs are rotating gas discs forming at z=0, that have undergone less than a revolution.

- IF these discs are in dynamical equilibrium:
  No DM & deviation from the BTF relation