

Tidal Dwarf Galaxies vs streams vs satellites

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Atlas3D, NGVS and MATLAS team

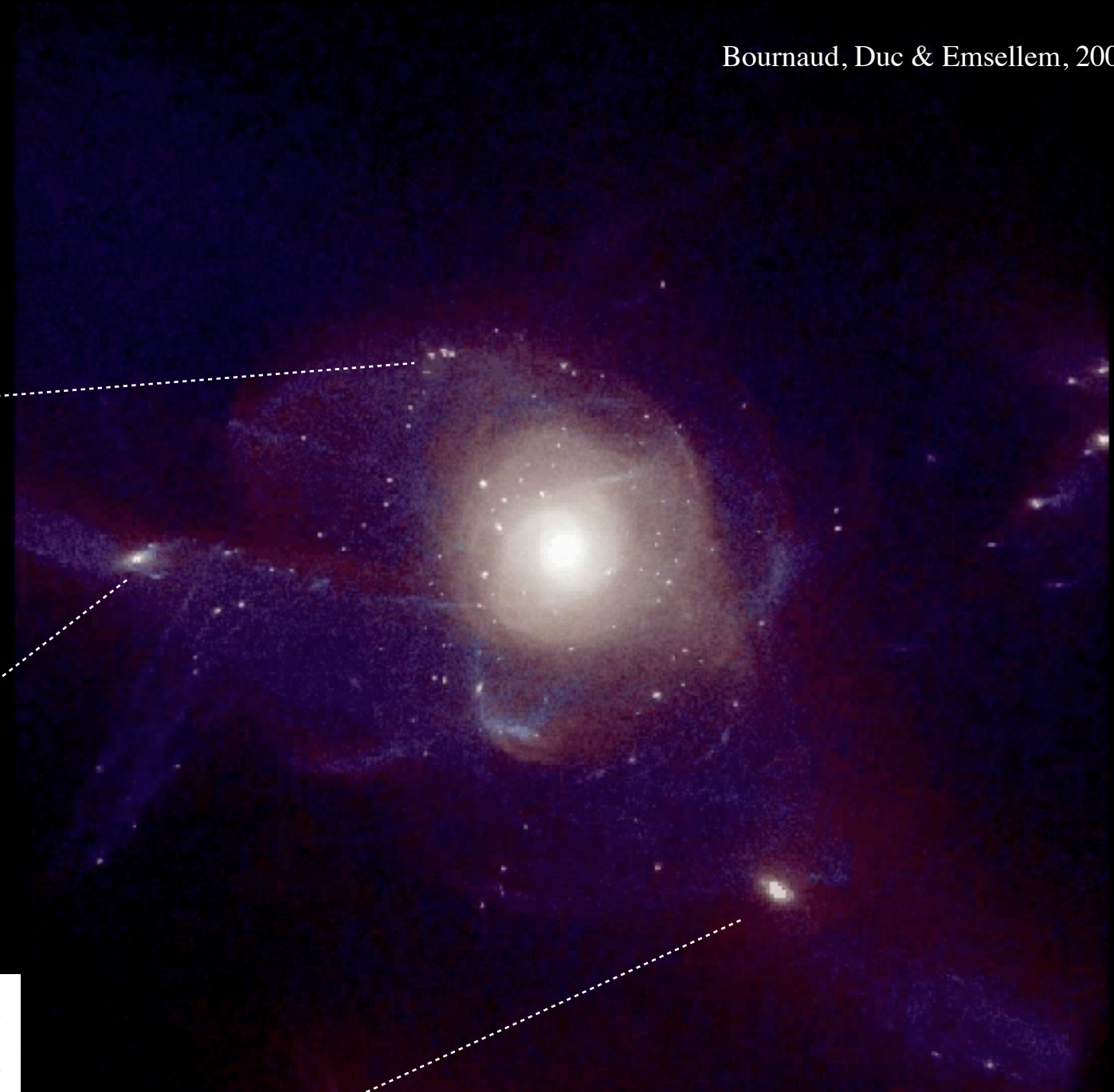
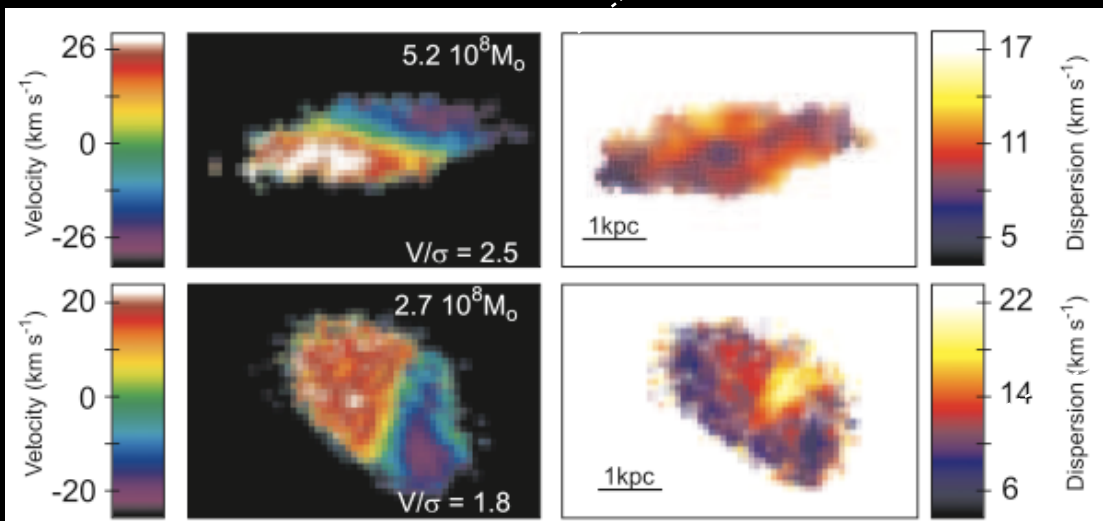
Defining Tidal Dwarf Galaxies

Bournaud, Duc & Emsellem, 2008

Various stellar objects
produced in galaxy mergers:

- Pressure supported objects:
SSCs (-> GCs, UCDs)

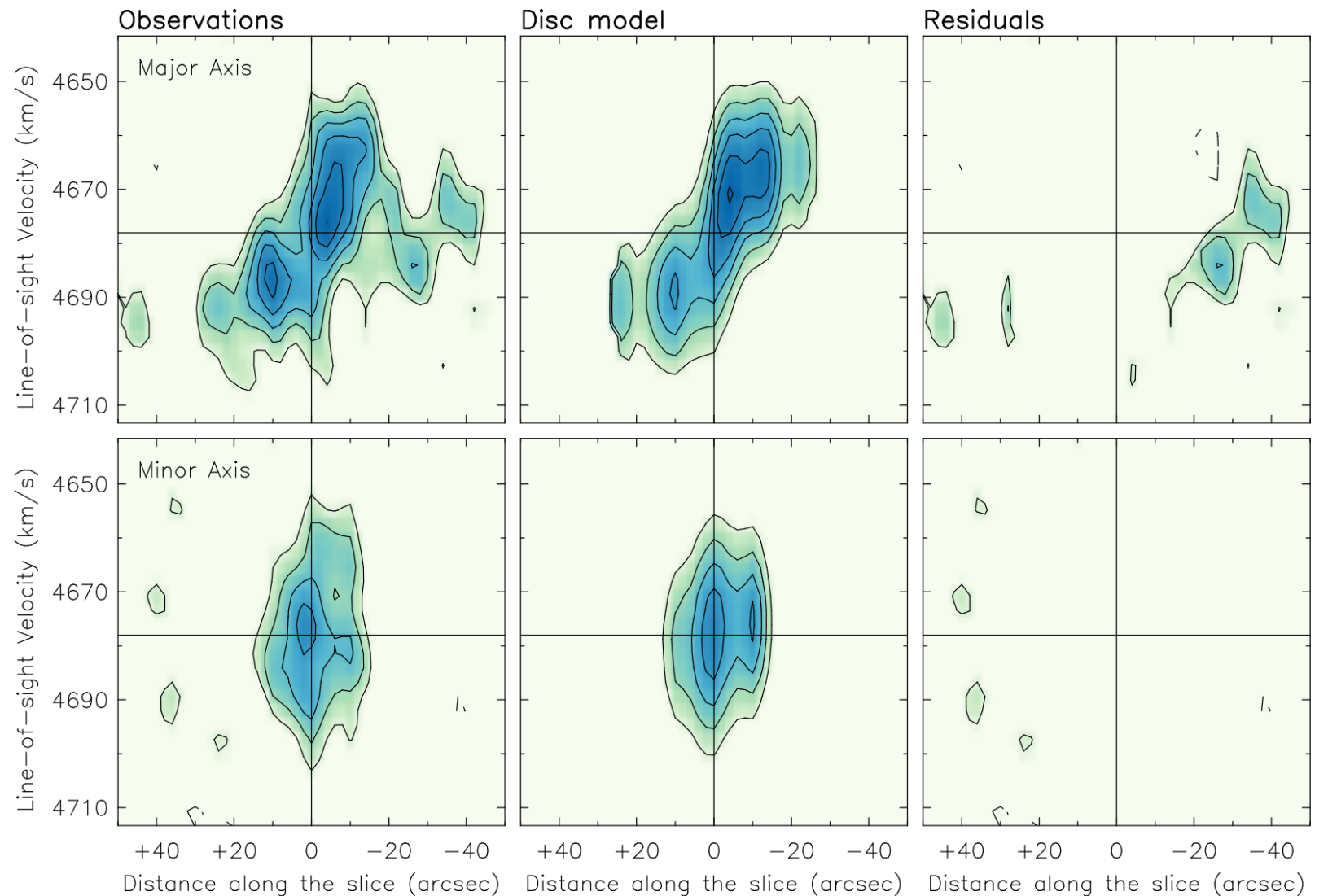
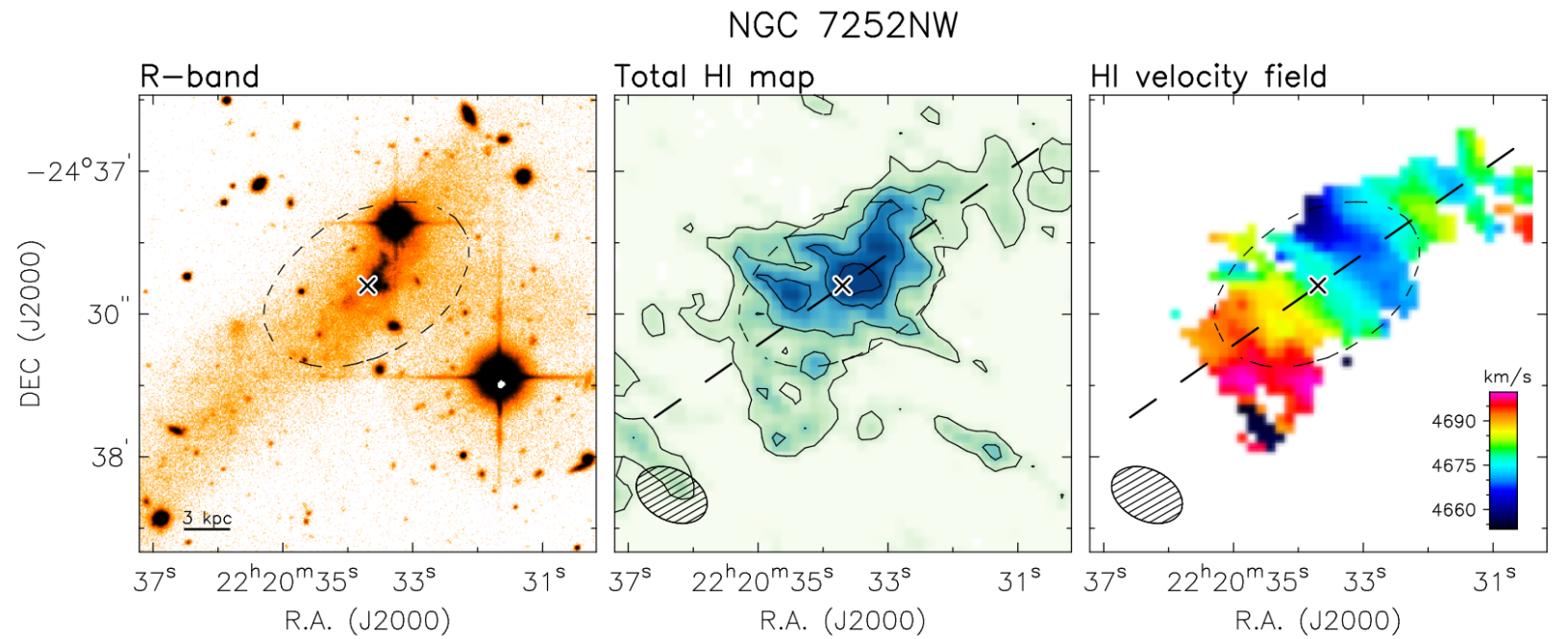
- **TDGs** are massive
gravitationally bound,
initially rotating objects
formed within collisional
debris



40 million particles
(gas: sticky)
20 pc resolution

Kinematics of Tidal Dwarf Galaxies

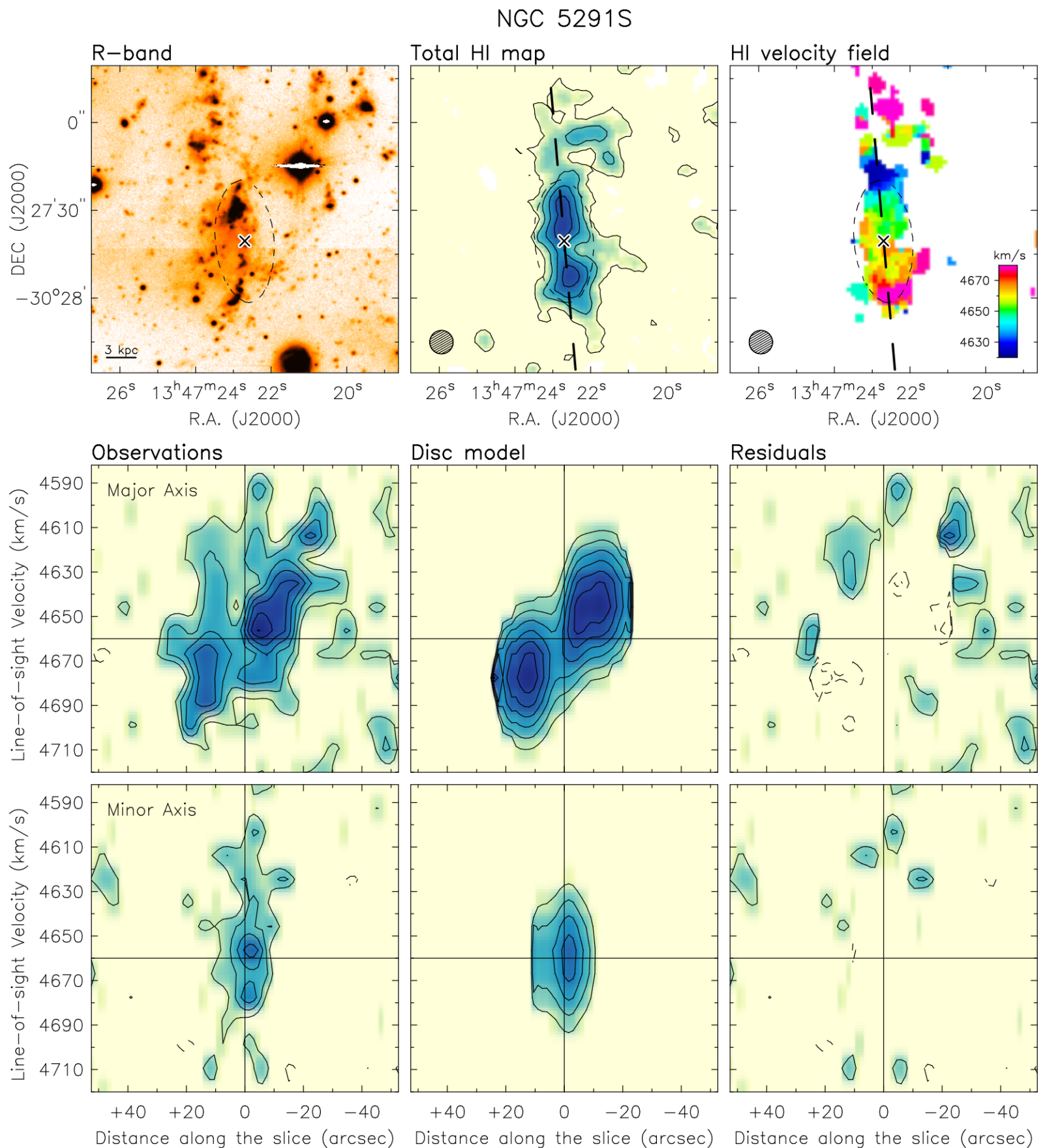
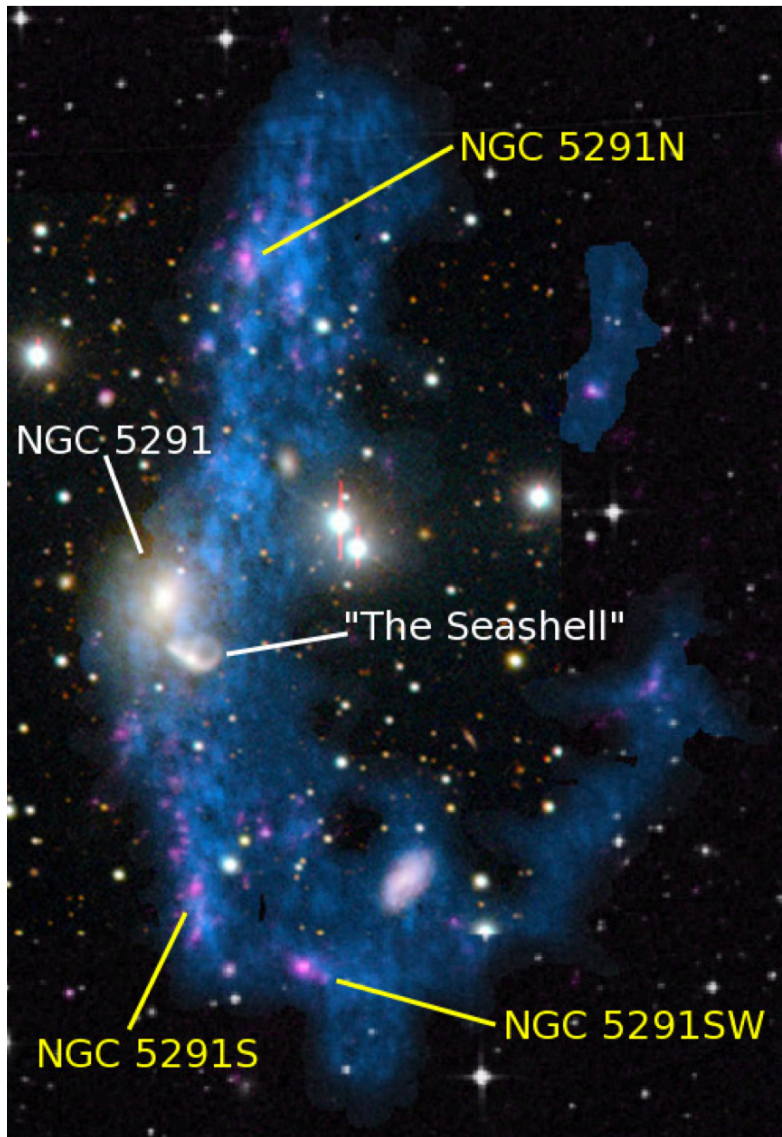
- High resolution HI VLA / B array data



- Kinematic model

Lelli et al 2015

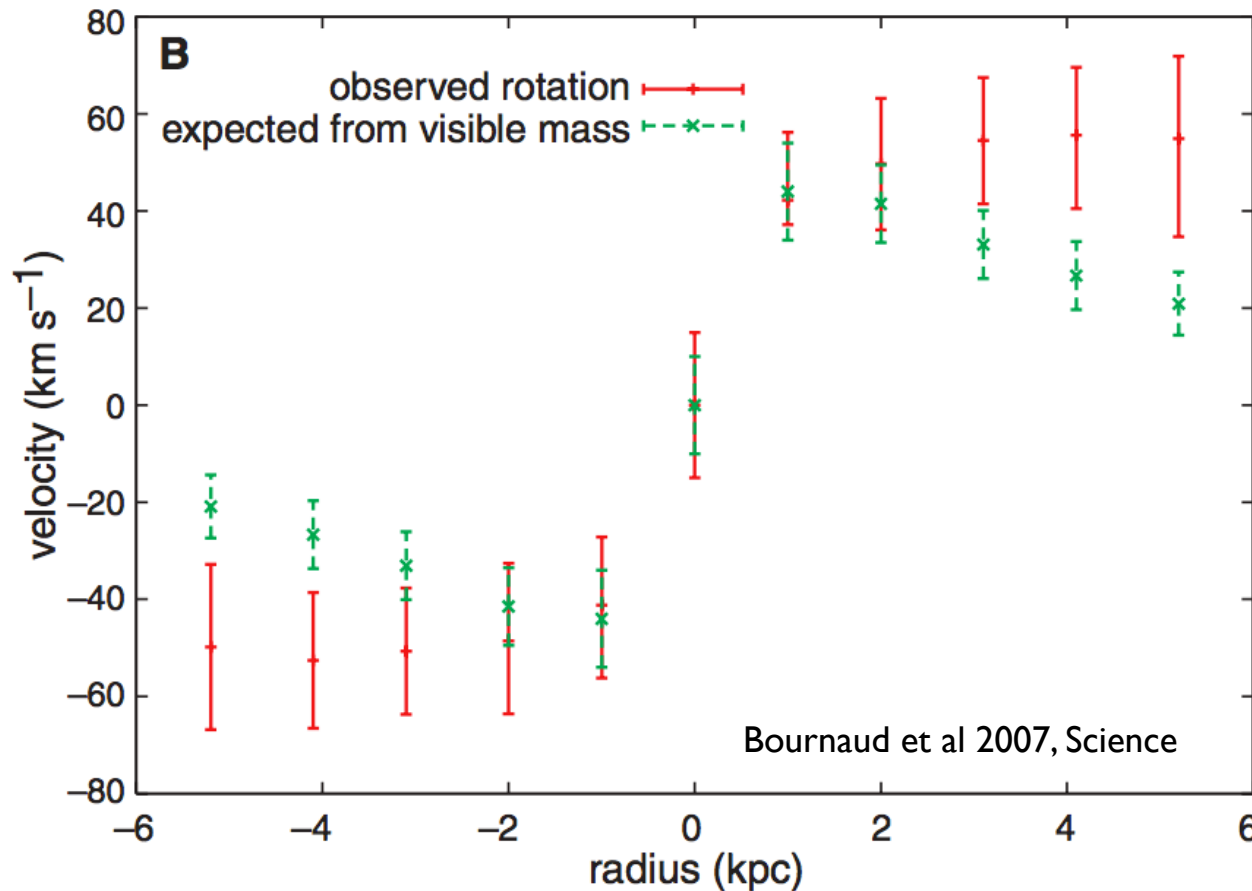
Kinematics of Tidal Dwarf Galaxies



Lelli et al 2015

- Evidence that collisional debris host kinematically decoupled rotating discs

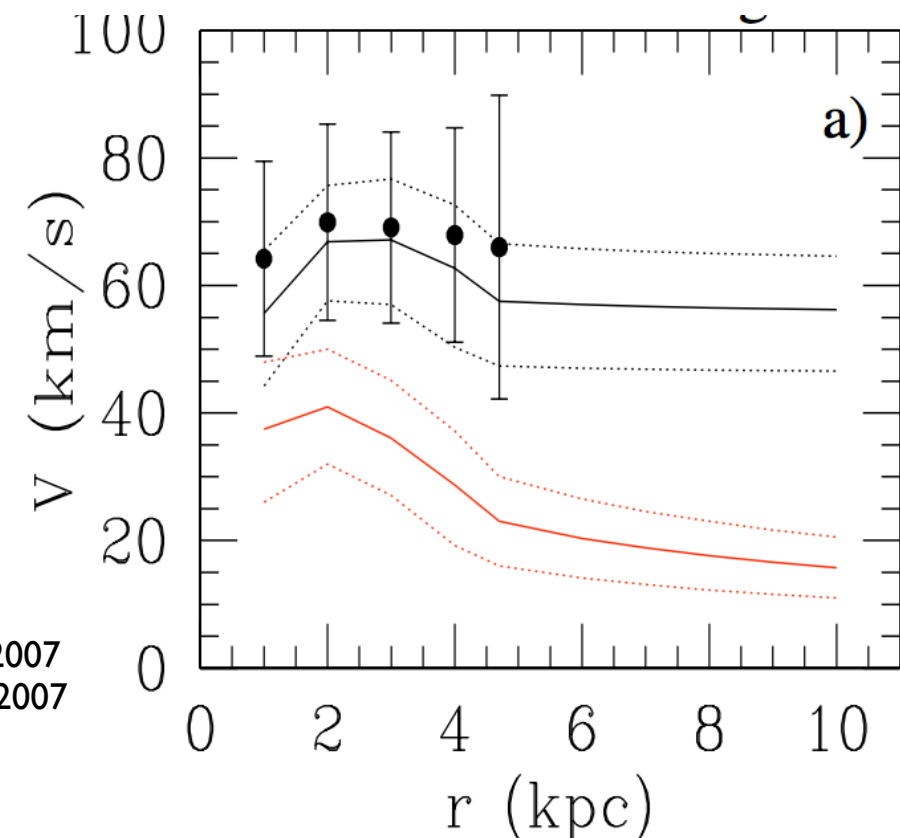
Kinematics of Tidal Dwarf Galaxies: a dark component?



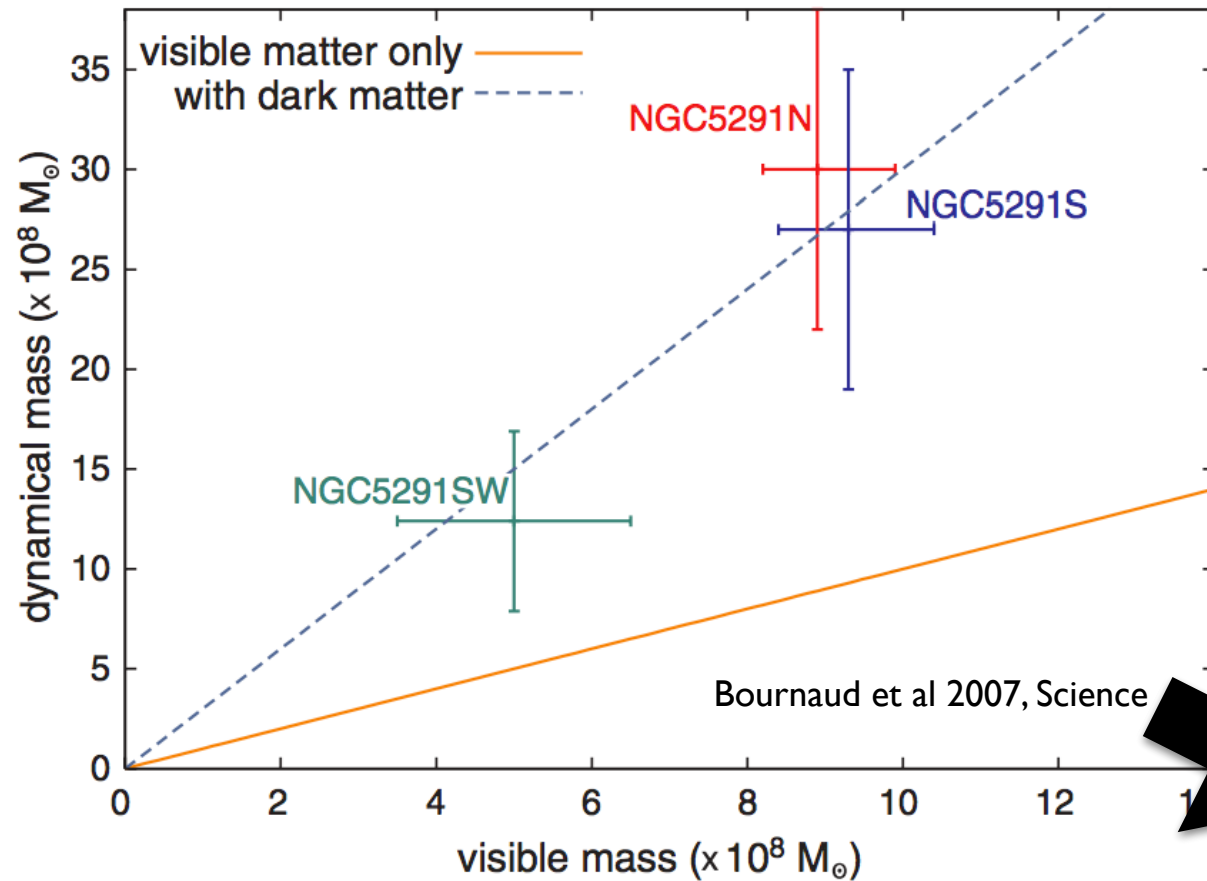
- TDGs are predicted to be dark matter poor (cosmological DM originally located in the halo)
- A claim for the presence of a dark (baryonic) component from the PV analysis of dwarfs in NGC 5291

- Alternative solution: MOND predicts a deviation with respect to the Keplerian rotation curve

Gentile et al., 2007
Milgrom et al., 2007



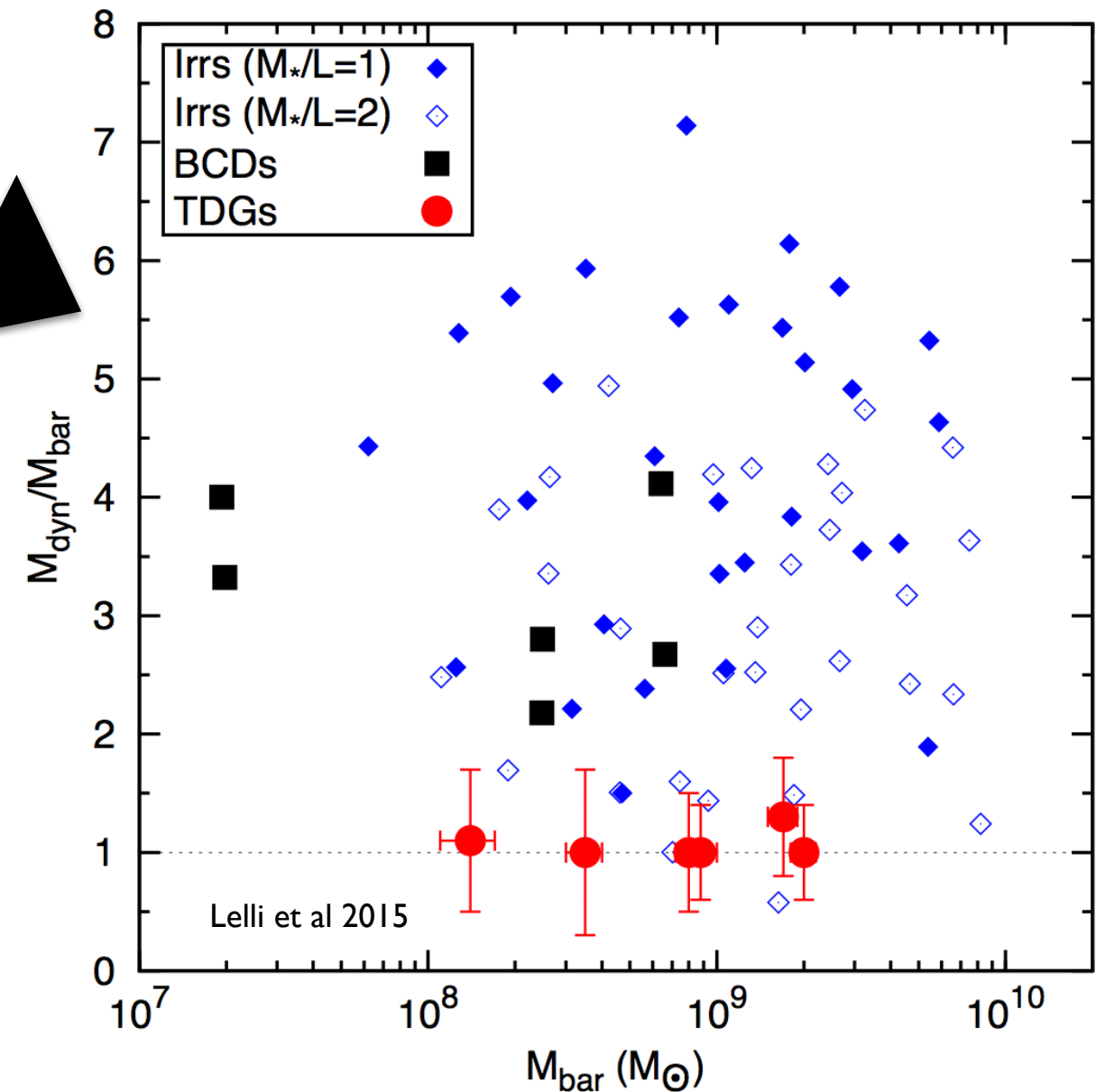
Kinematics of Tidal Dwarf Galaxies: a dark component?



• $M_{\text{dyn}} / M_{\text{vis}} = 3$

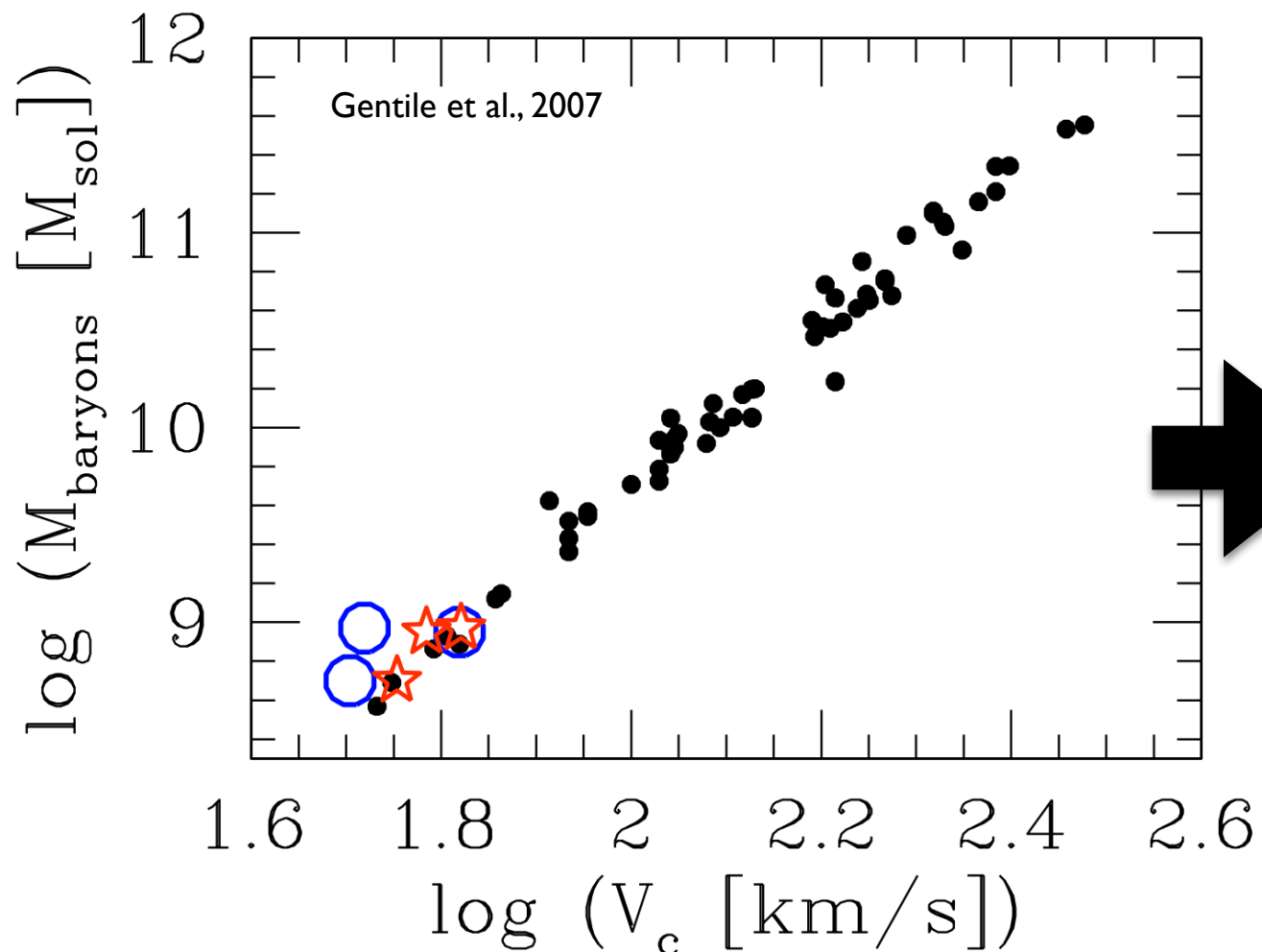
• $M_{\text{dyn}} / M_{\text{vis}} = 1$

• Our latest analysis, with disc model, do not confirm the presence of a significant dark component

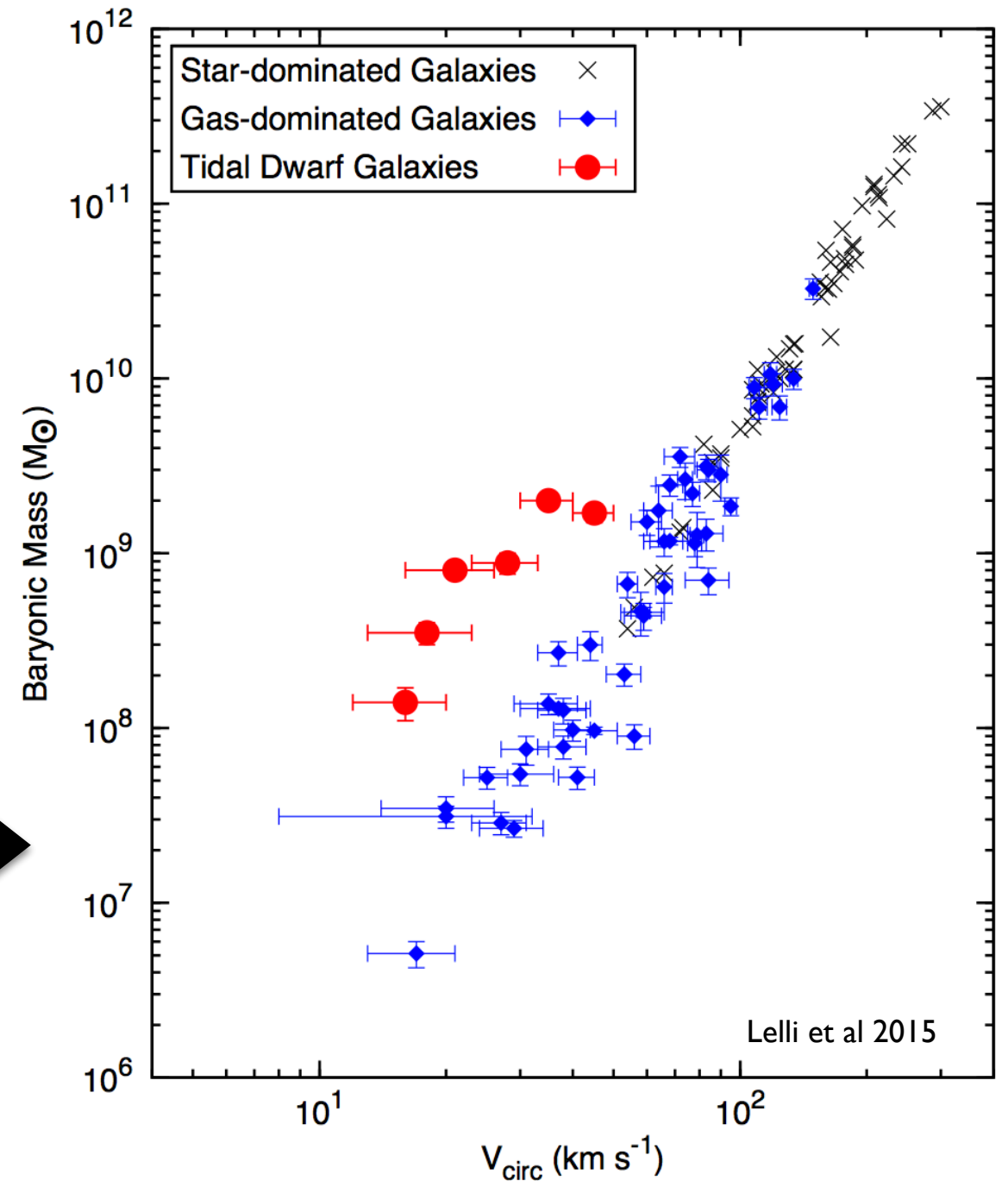


Kinematics of Tidal Dwarf Galaxies: MOND?

- Baryonic Tully-Fisher relation



- No deviation expected in the MOND framework



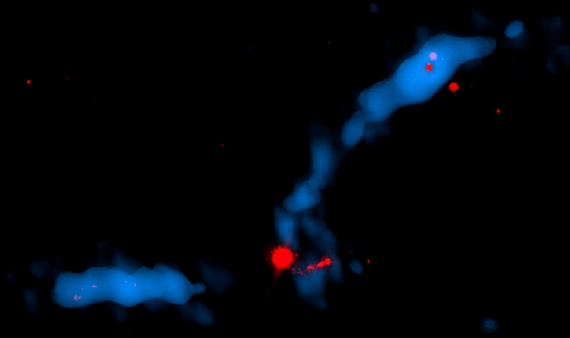
- TDGs seem to deviate from the baryonic Tully-Fischer relation

Formation of Tidal Dwarf Galaxies



Bournaud, Duc & Emsellem, 2008

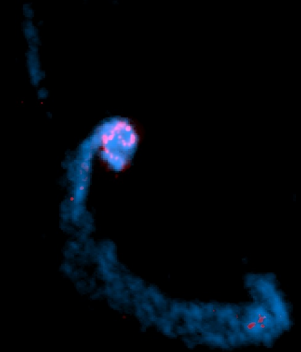
40 million particles
(gas: sticky)
20 pc resolution
NGC 7252 - like



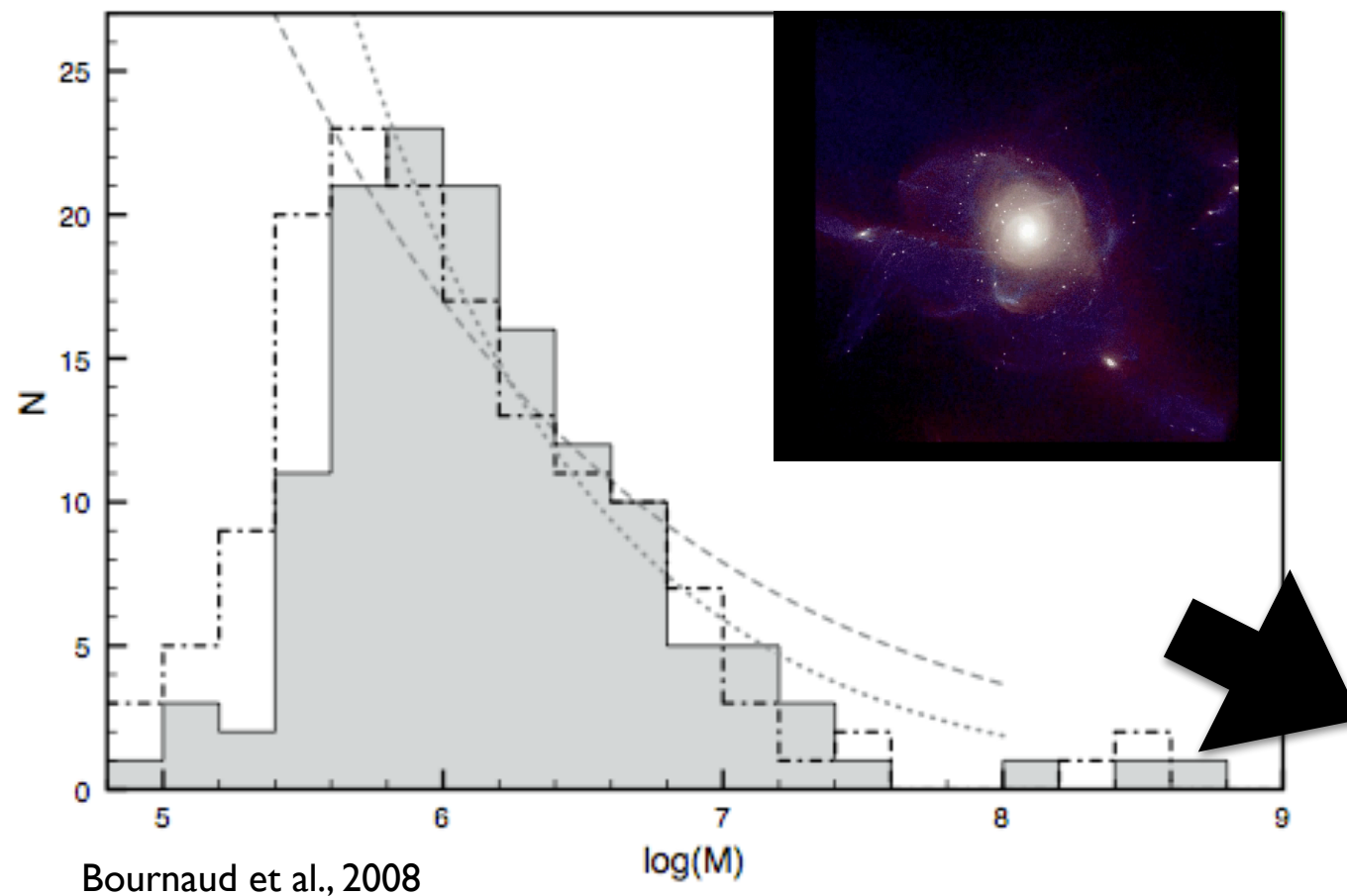
Renaud et al., 2015

Hydrodynamical
AMR (Ramses)
2 pc resolution
Antennae-like

See talk by F. Renaud



Formation of Tidal Dwarf Galaxies

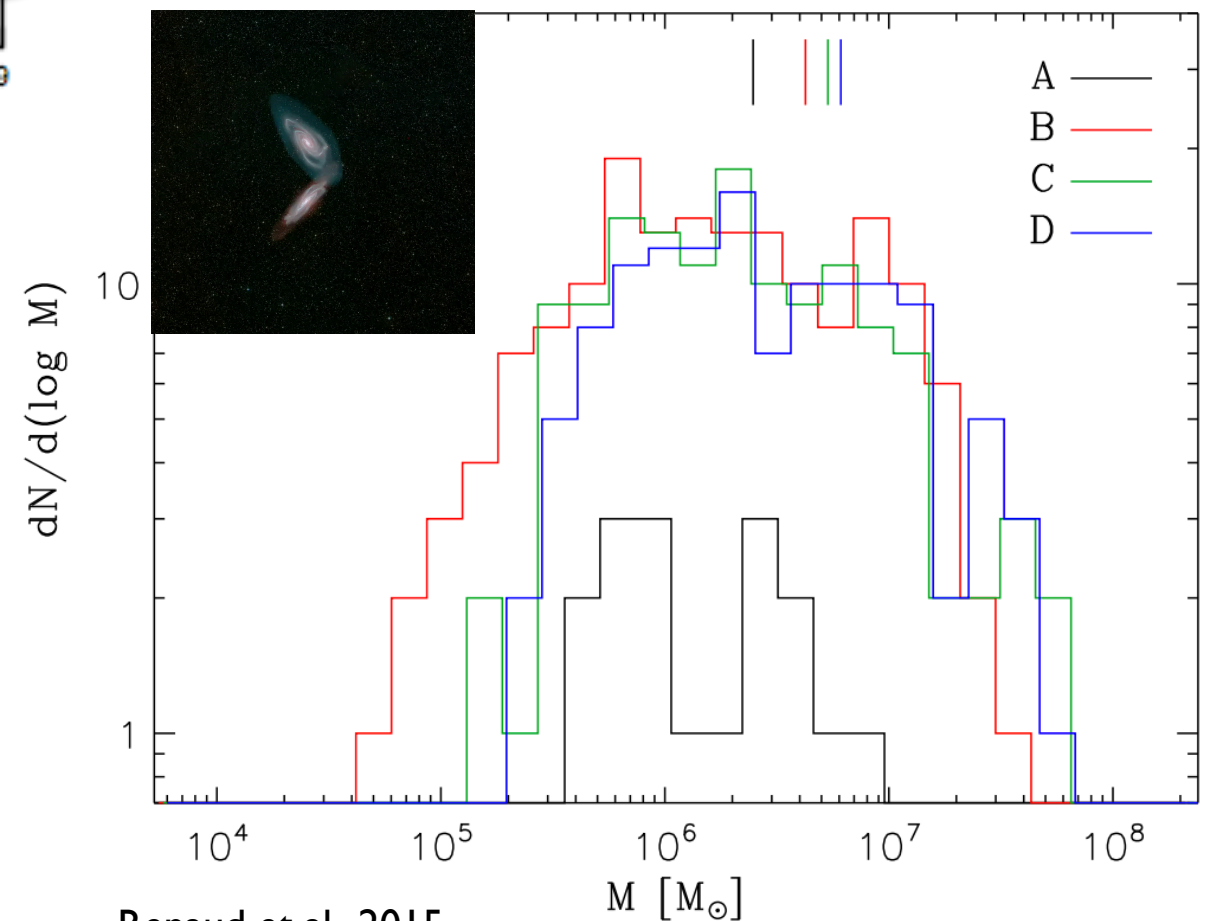


Cluster mass function

- NGC7252-like simulation** (Sticky particle)
- A bi-modality of the CMF due to TDGs?

Antennae-like simulation (Hydro, RAMSES)

- No evidence for extended massive TDGs



- *Mostly young TDGs have yet been unambiguously identified*
- *Numerical simulations predict that a fraction of them should survive as satellite galaxies* **see talk by S. Ploeckinger**
- *The observational quest for old TDGs still on going*
- *Several criteria to be met simultaneously:*

✓ **Structural diagnostic**: low dark matter content

Method:

kinematical measurements:

- width of CO lines
- rotational curves (HI, H α)
- stellar velocity dispersion
- deviation from baryonic TF relation

✓ **Paternity test**: measure of an excess of heavy elements, inherited from their parent galaxies

Method:

- measure of oxygen abundance in the ionized gas
- detection of molecular gas
- measure of the metallicity of stellar populations

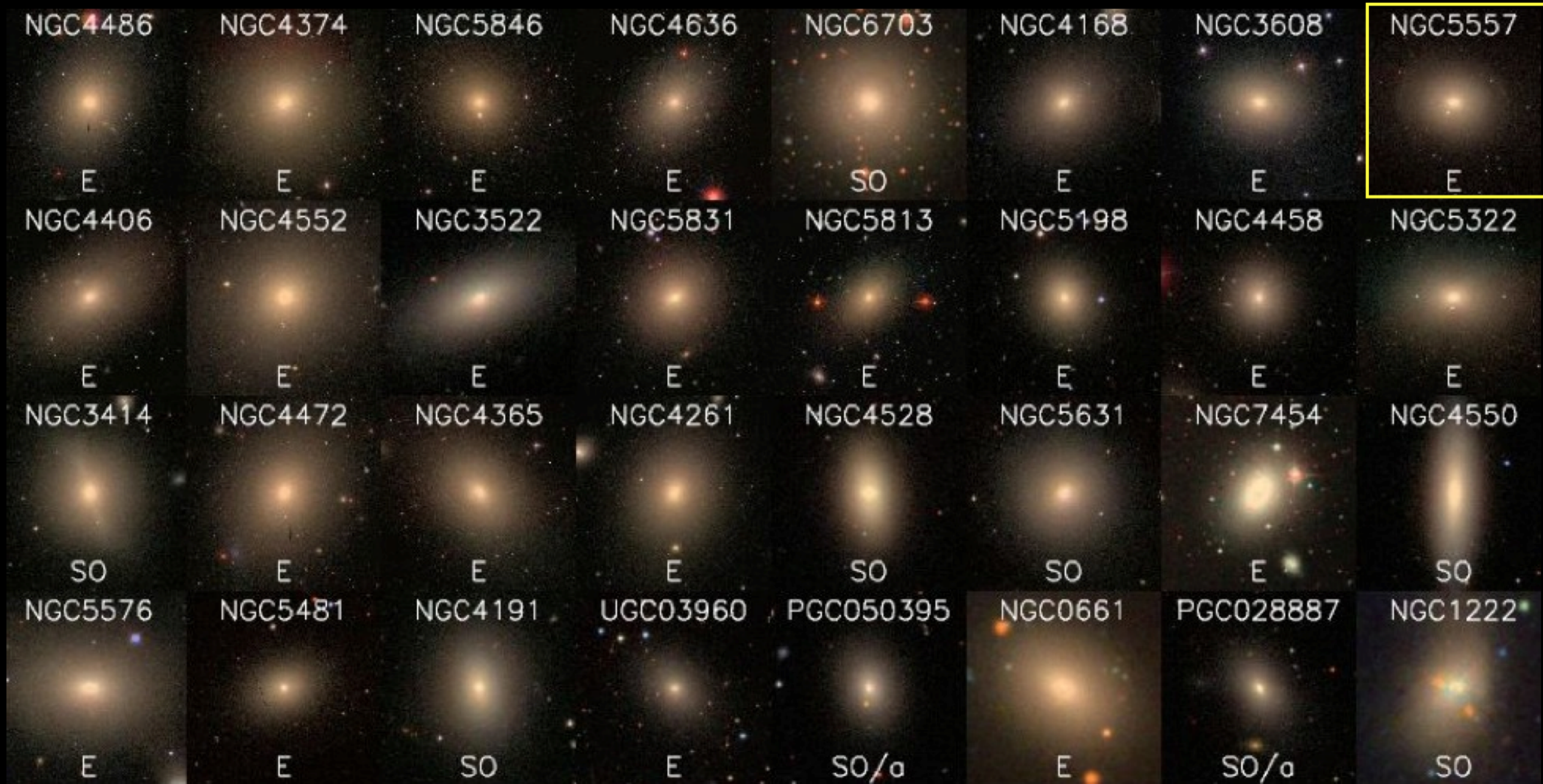
✓ **Location**: look for TDGs in favorable

environments:

groups, cluster of galaxies, vicinity of early type galaxies

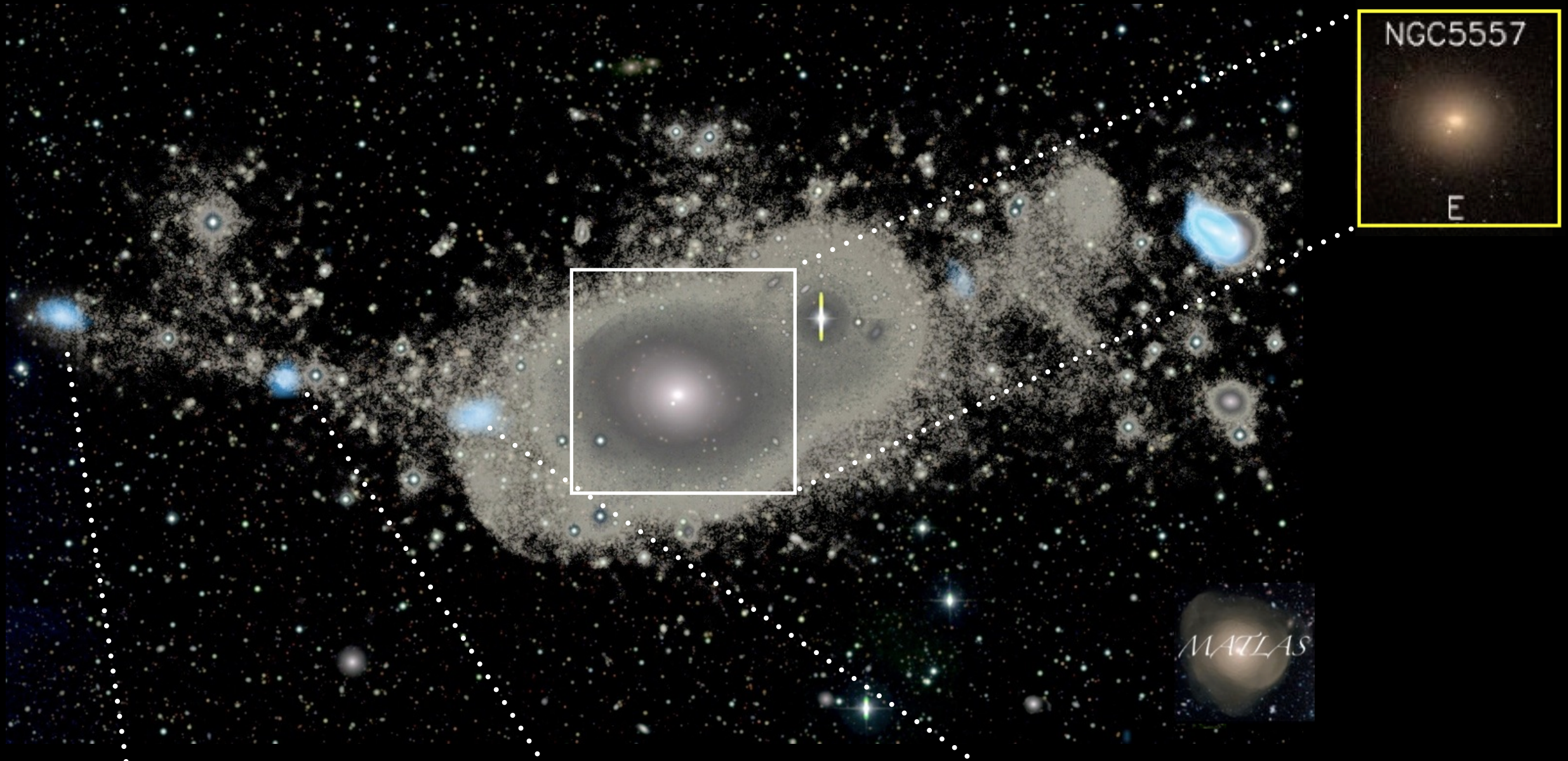
(preferentially along their equatorial plane: disk of satellites)

Searching for old Tidal Dwarf Galaxies around massive ellipticals



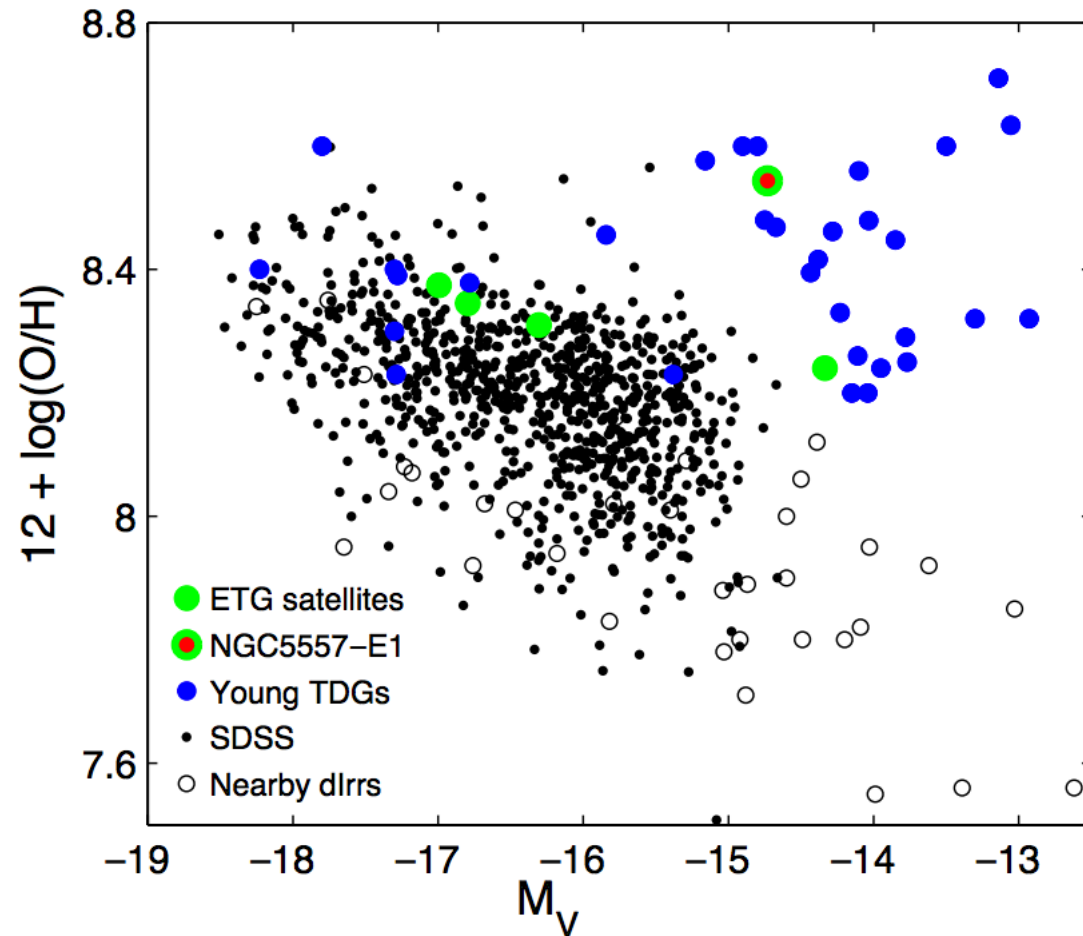
Duc, et al., 2015

Searching for old Tidal Dwarf Galaxies around massive ellipticals



Duc, et al. , 2014

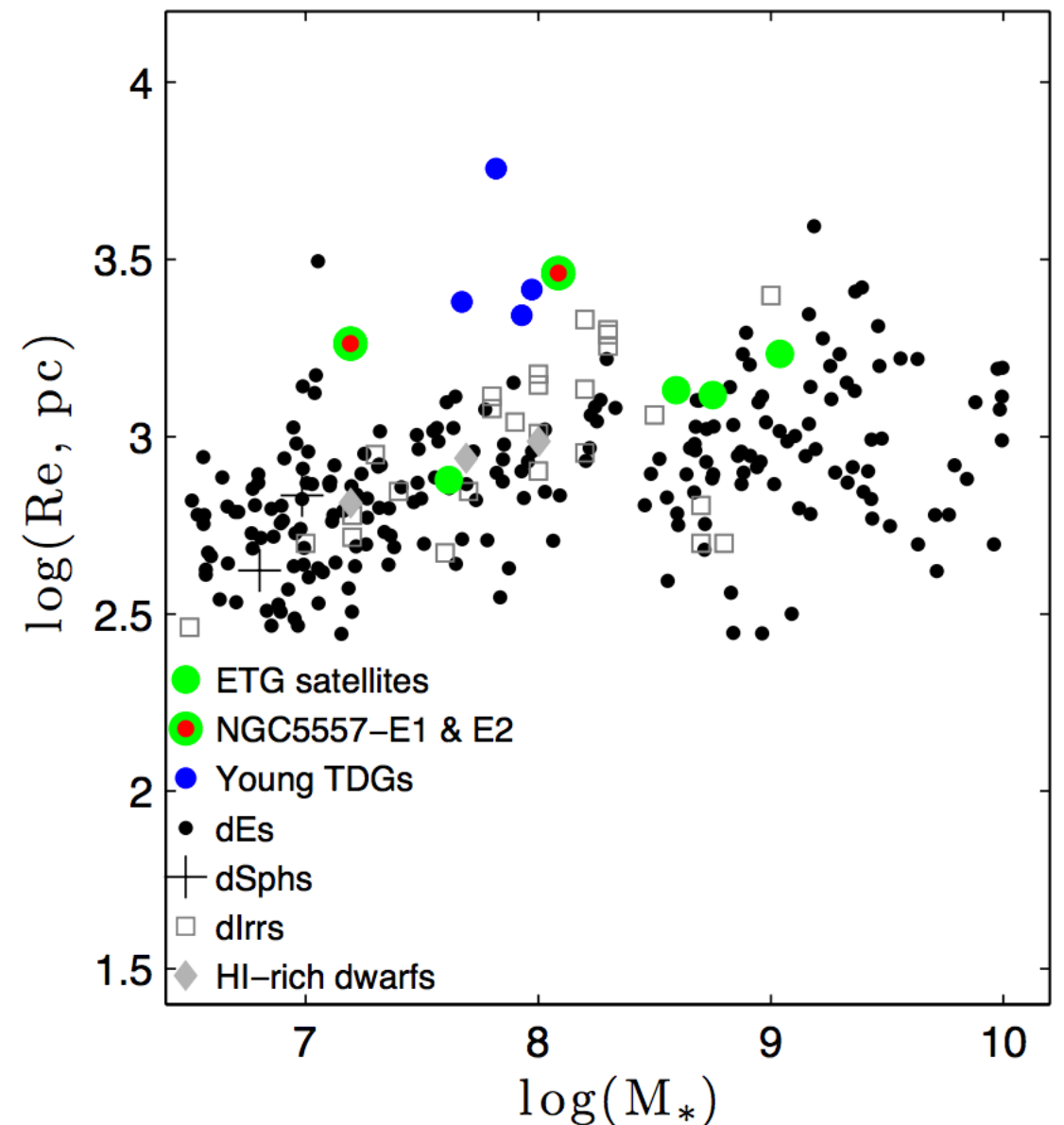
Case of >2 Gyr old Tidal Dwarf Galaxies



✓ Paternity test: confirmed high metallicity

An additional criterion to investigate a tidal origin:

✓ a large effective radius (>2 kpc), even for old TDGs



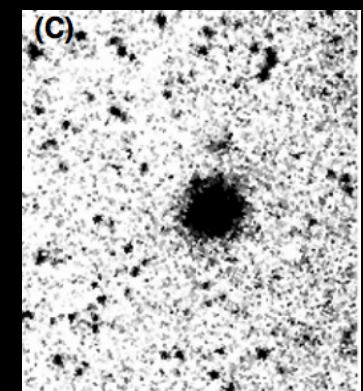
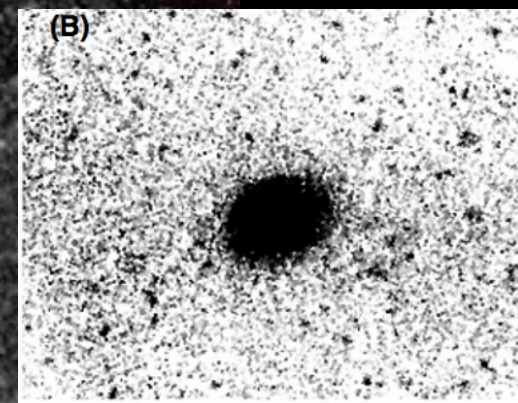
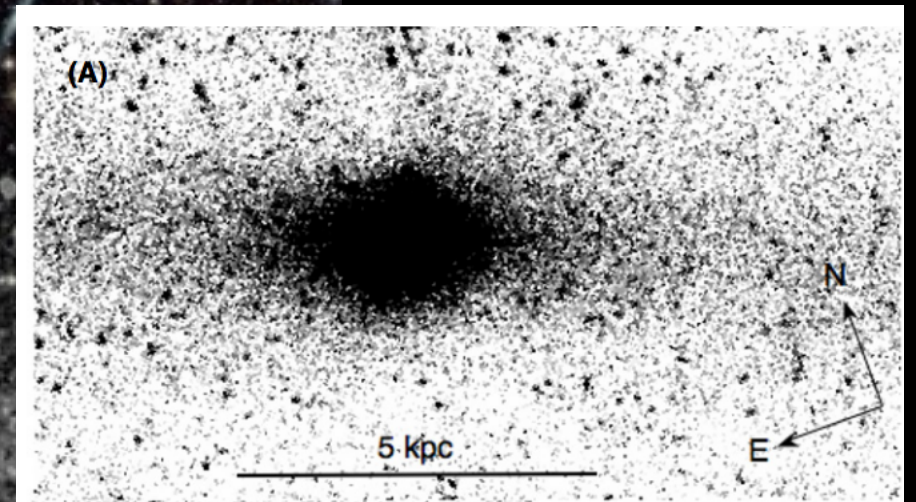
Tidal Dwarf Galaxies and streams: newly born or pre-existing?



Streams with S-shape:
likely pre-existing stripped dwarfs

Tidal Dwarf Galaxies and streams: newly born or pre-existing?

Strange alignment
of dwarf galaxies,
with large effective
radius: TDGs or
disrupted dwarf
galaxies?

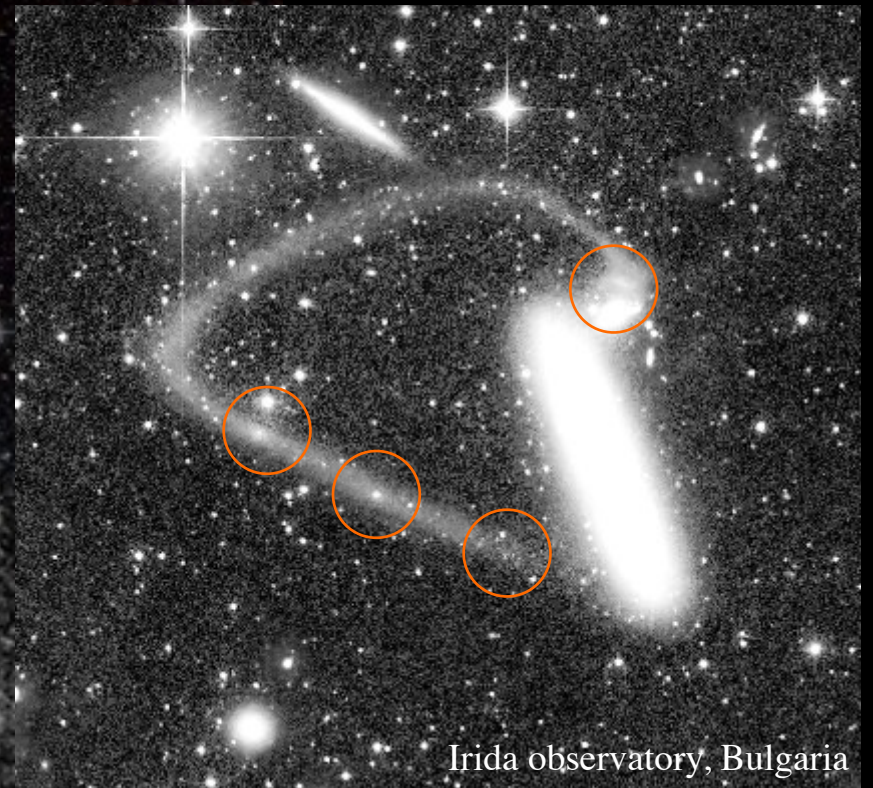


Paudel, Duc et al., 2013



Tidal Dwarf Galaxies and streams: newly born or pre-existing?

Strange alignment
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Irida observatory, Bulgaria

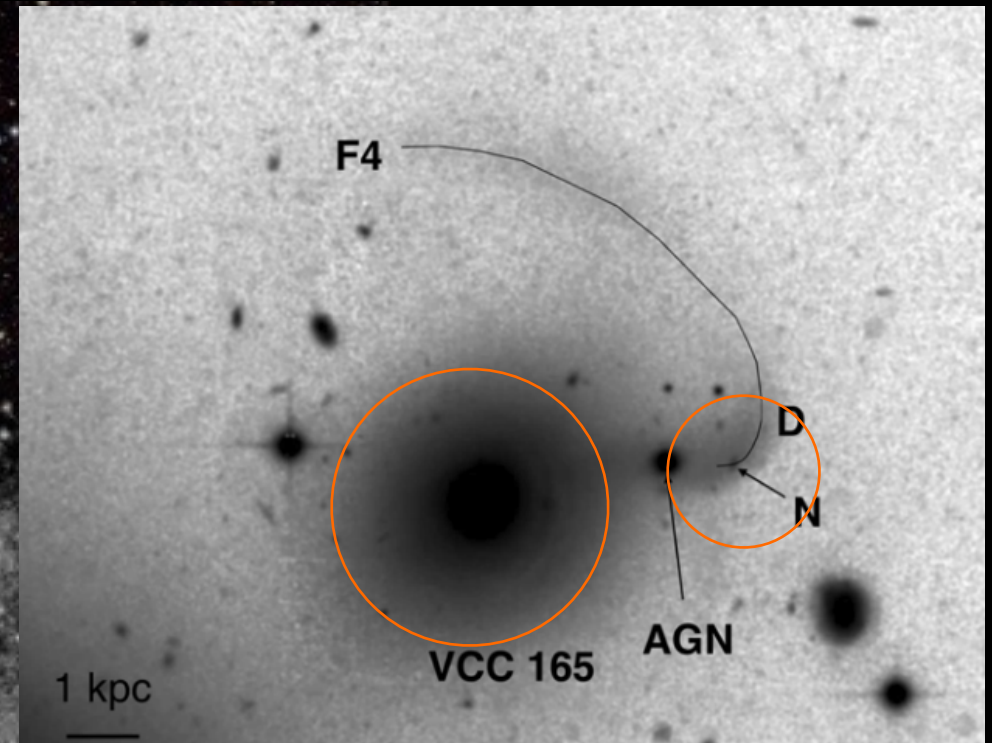
4 dwarfs aligned,
3 at same velocity



Paudel, Duc et al., 2013

Tidal Dwarf Galaxies and streams: newly born or pre-existing?

Strange alignment
of dwarf galaxies,
with large effective
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disrupted dwarf
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A satellite of a
satellite



Paudel, Duc et al., 2013

Back to the local group: M31 disk of satellites

Are they old TDGs?

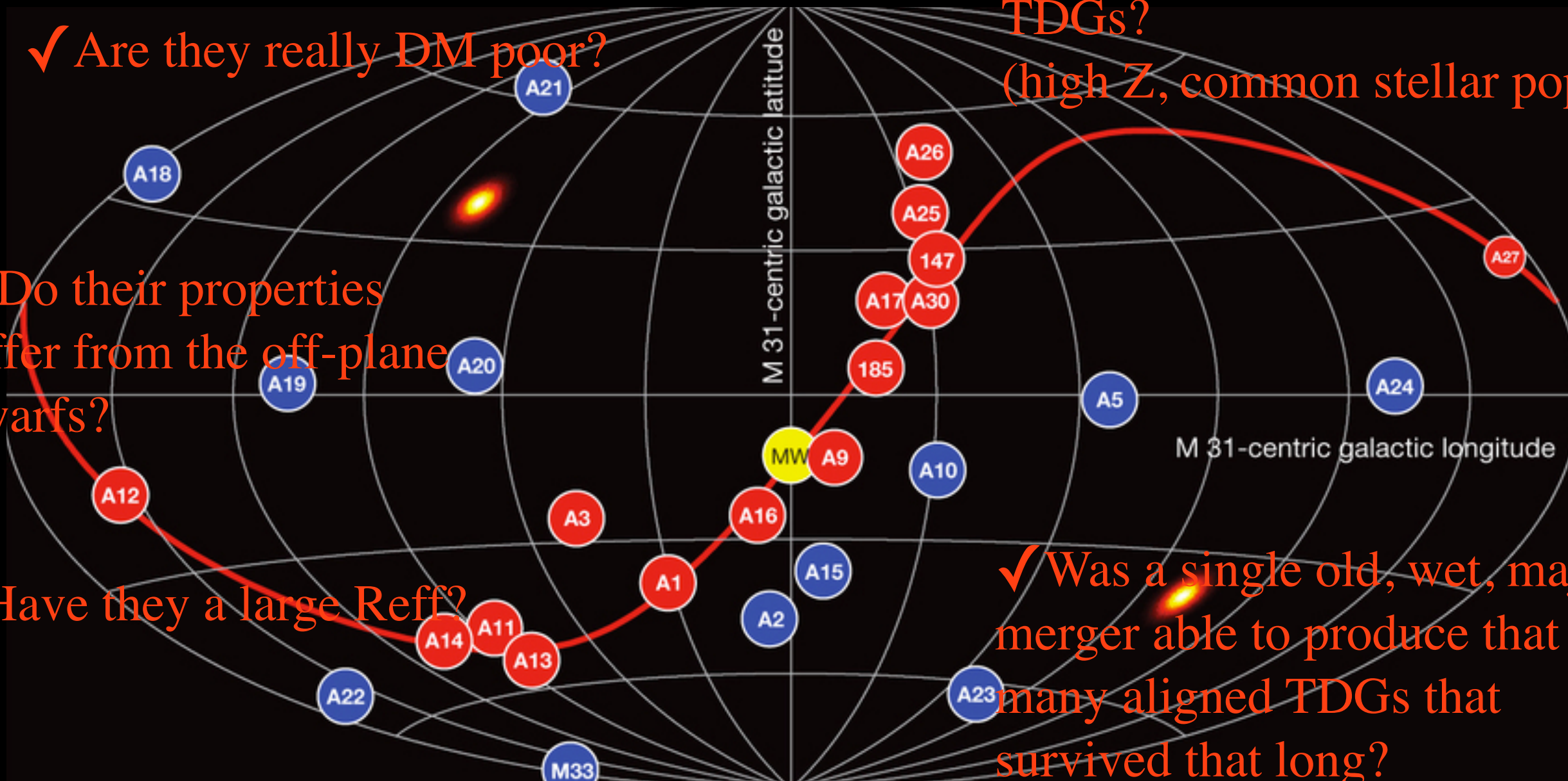
✓ Have they the genes of TDGs?
(high Z, common stellar pops)

✓ Are they really DM poor?

✓ Do their properties differ from the off-plane dwarfs?

✓ Have they a large R_{eff} ?

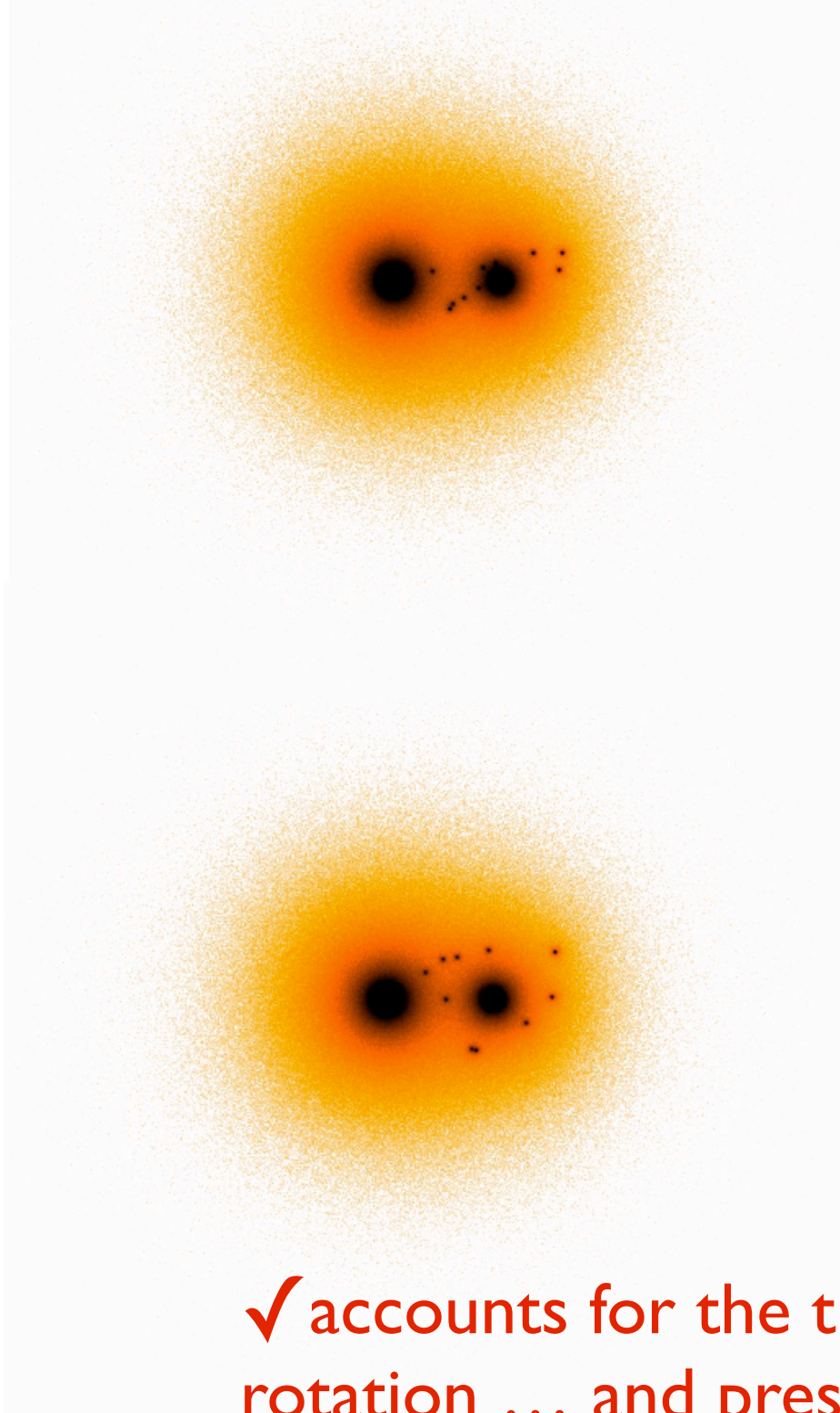
✓ Was a single old, wet, major merger able to produce that many aligned TDGs that survived that long?



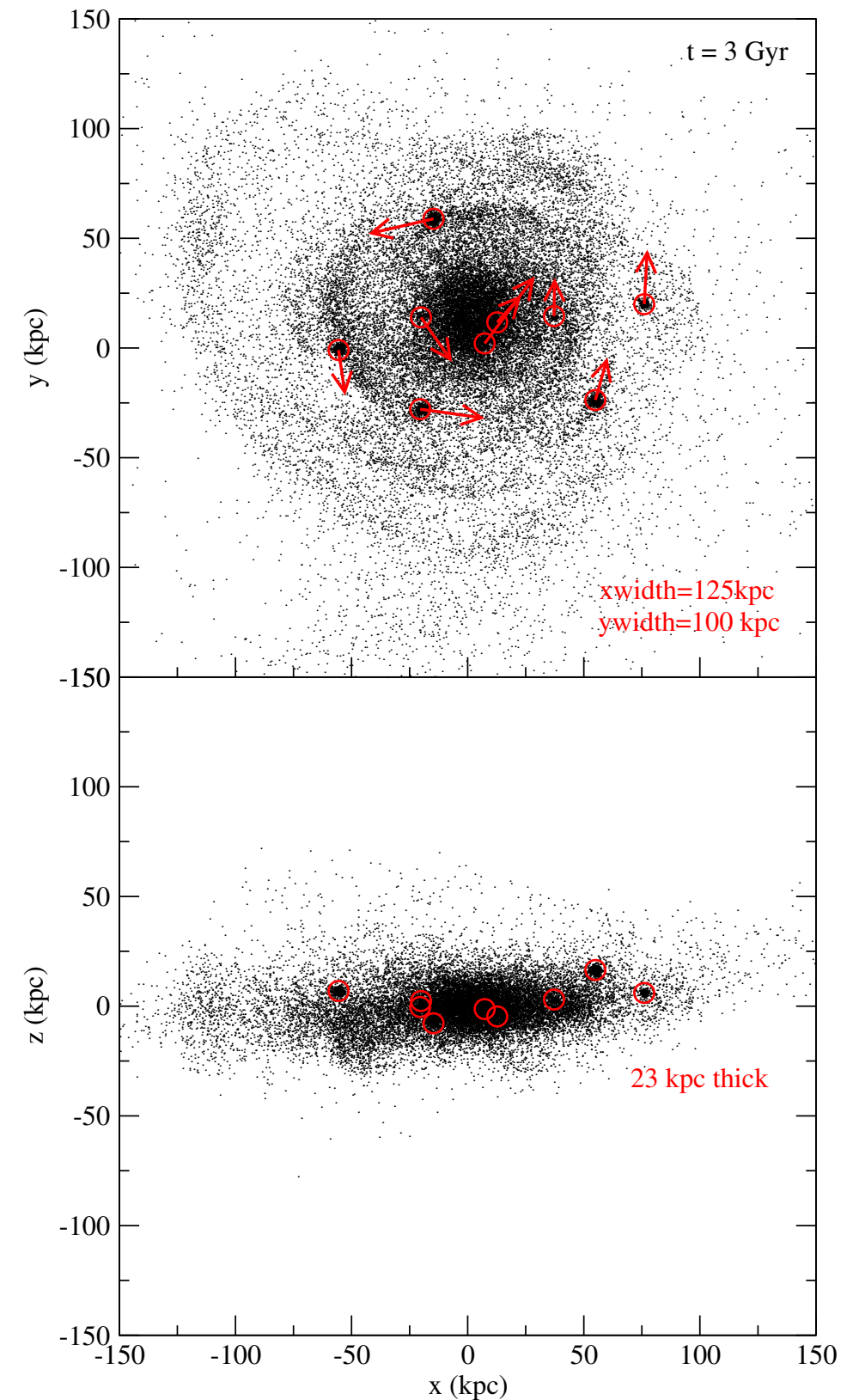
See talks/posters by Rodrigo Ibata, Marcel Pawlowski, Noam Libeskind, Tobias Goerdt, Veronica Arias

Origin for the disk of satellites of M3 I: an alternative scenario

Dwarfs accreted ... through a merger



✓ accounts for the thin disk, common rotation ... and presence of DM

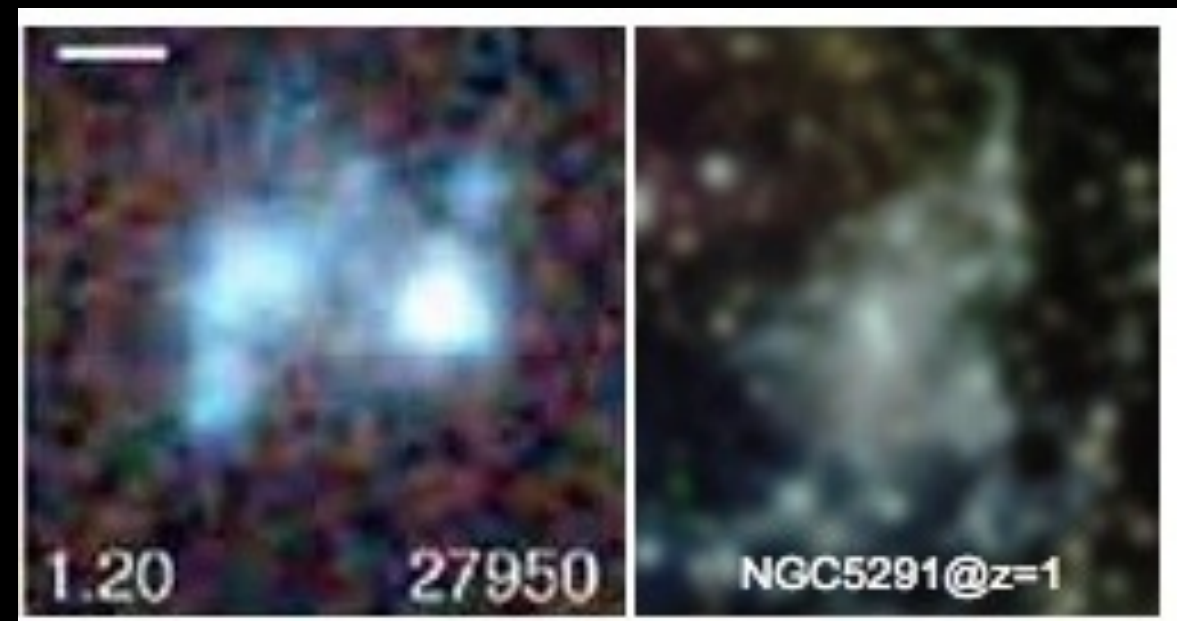


Smith & Duc 2015

TDGs as analogues to clumpy distant galaxies

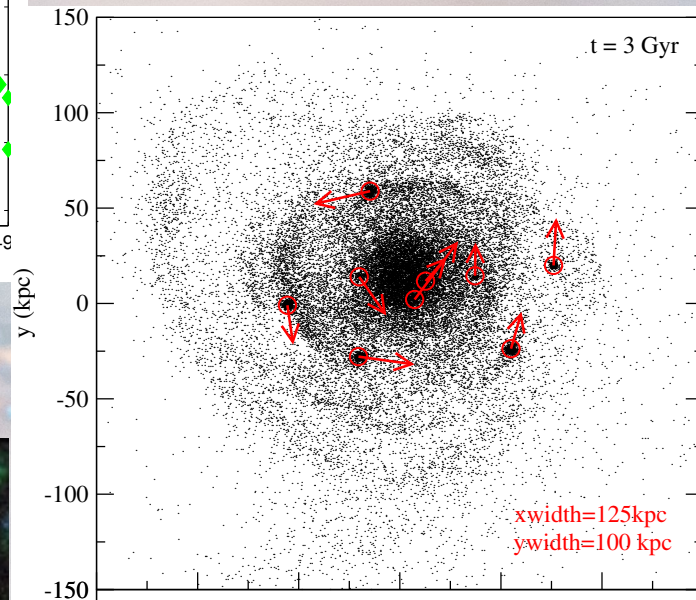
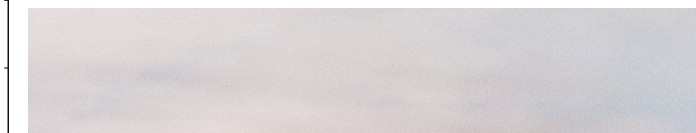
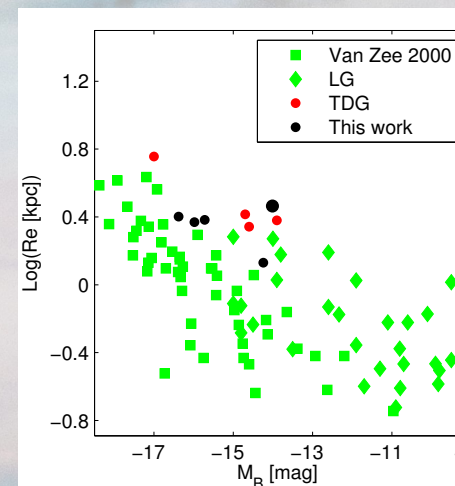
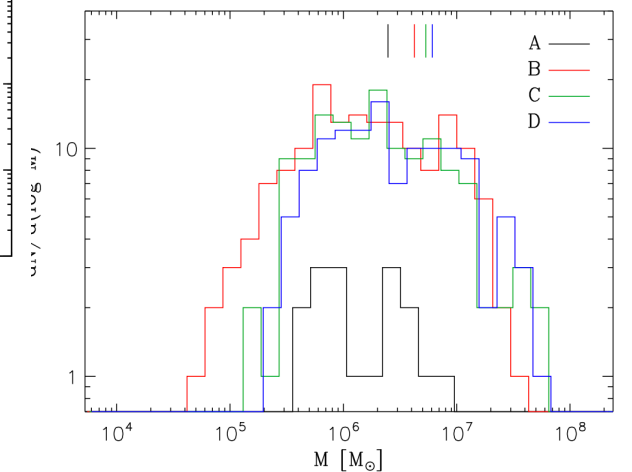
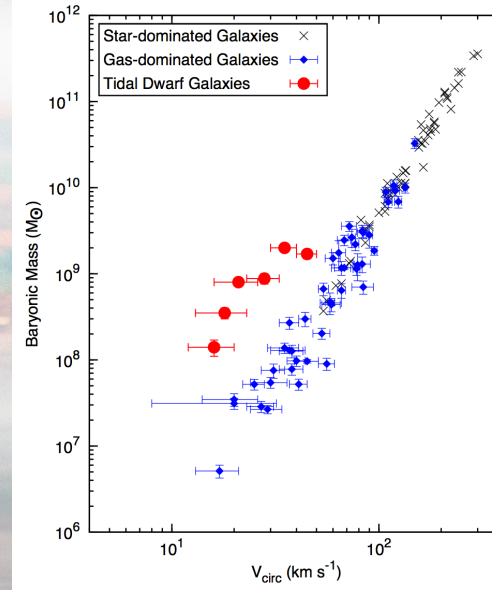


See poster by J. Fensch



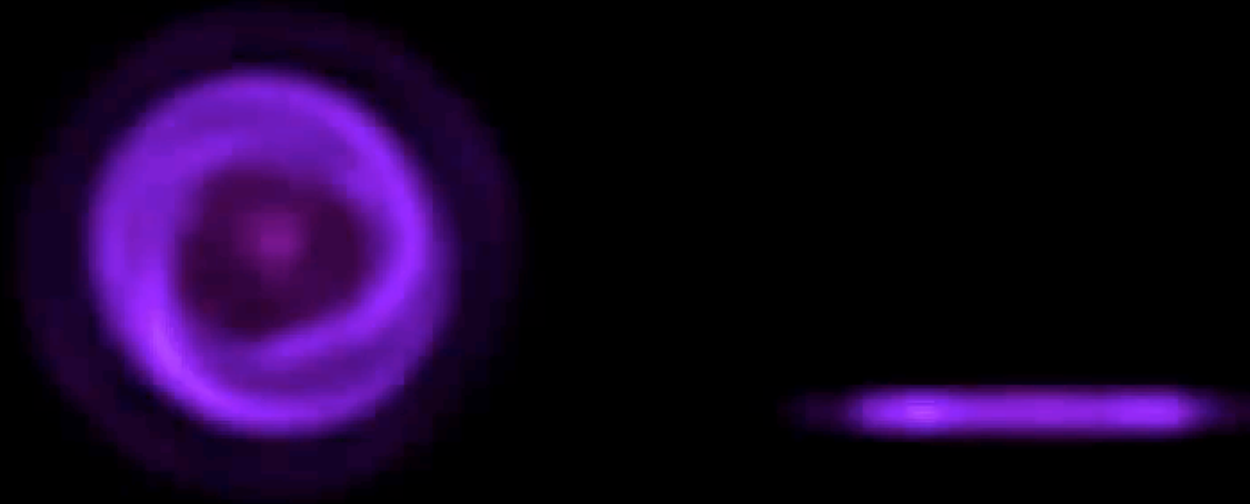
Conclusions

- **Structural properties** of Tidal Dwarf Galaxies
 - Initially gas-dominated, rotating, little DM (deviate from the baryonic TF relation)
- **Formation** of Tidal Dwarf Galaxies
 - Not all mergers from TDGs
- **Survival** of Tidal Dwarf Galaxies
 - evidence for a few long lived TDGs found, survey in progress
 - candidates in the Local Group controversial (alternative scenario mixing merger and cosmological accretion)
- TDGs as local **analogues** of distant gas-dominated galaxies

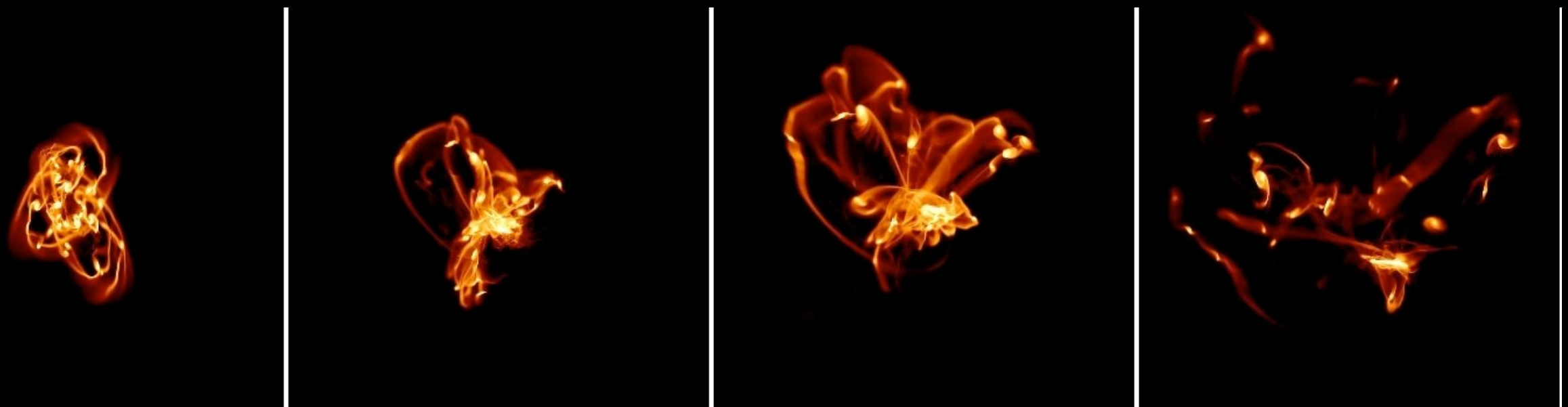


Tidal Dwarf Galaxies formation at high redshift

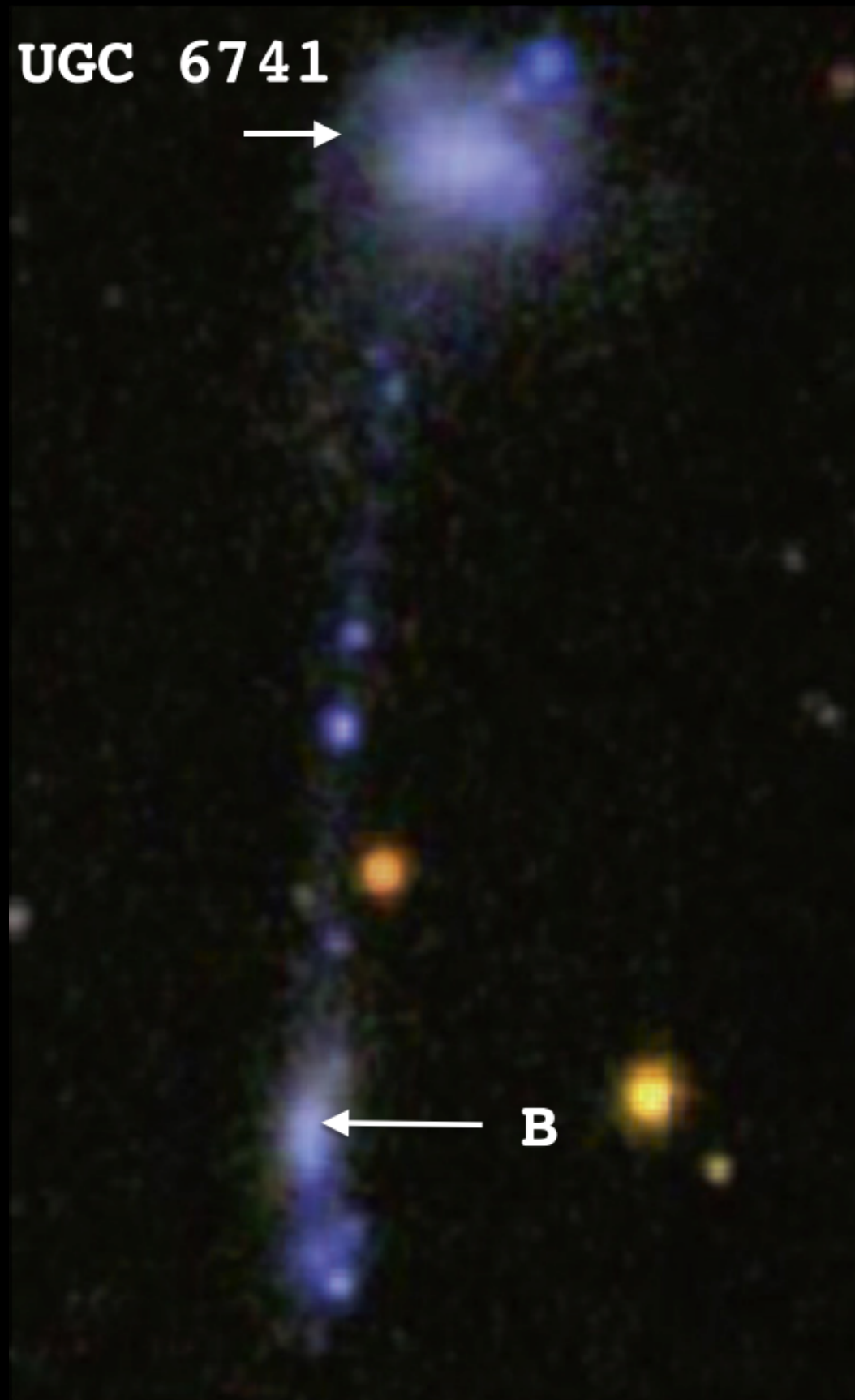
- More gas rich and unstable progenitors



➔ Their collision leads to the formation of numerous TDG-like objects ... but no tidal tails

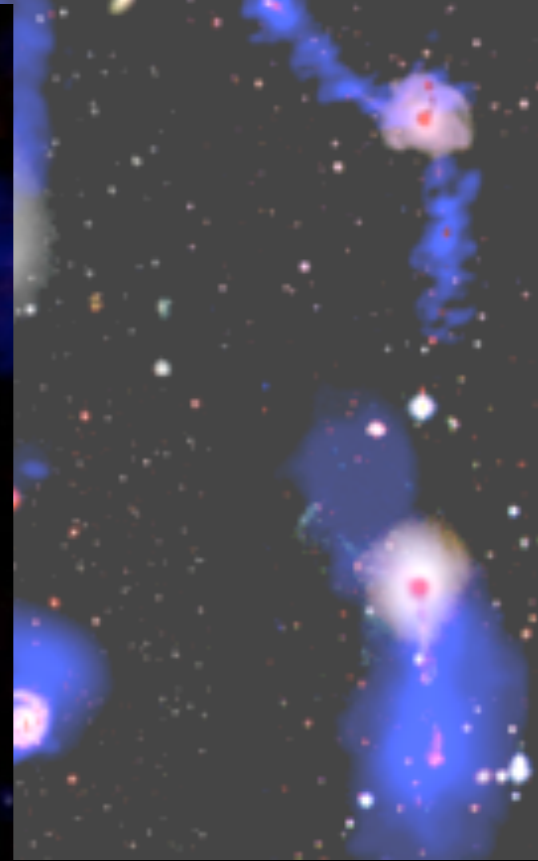
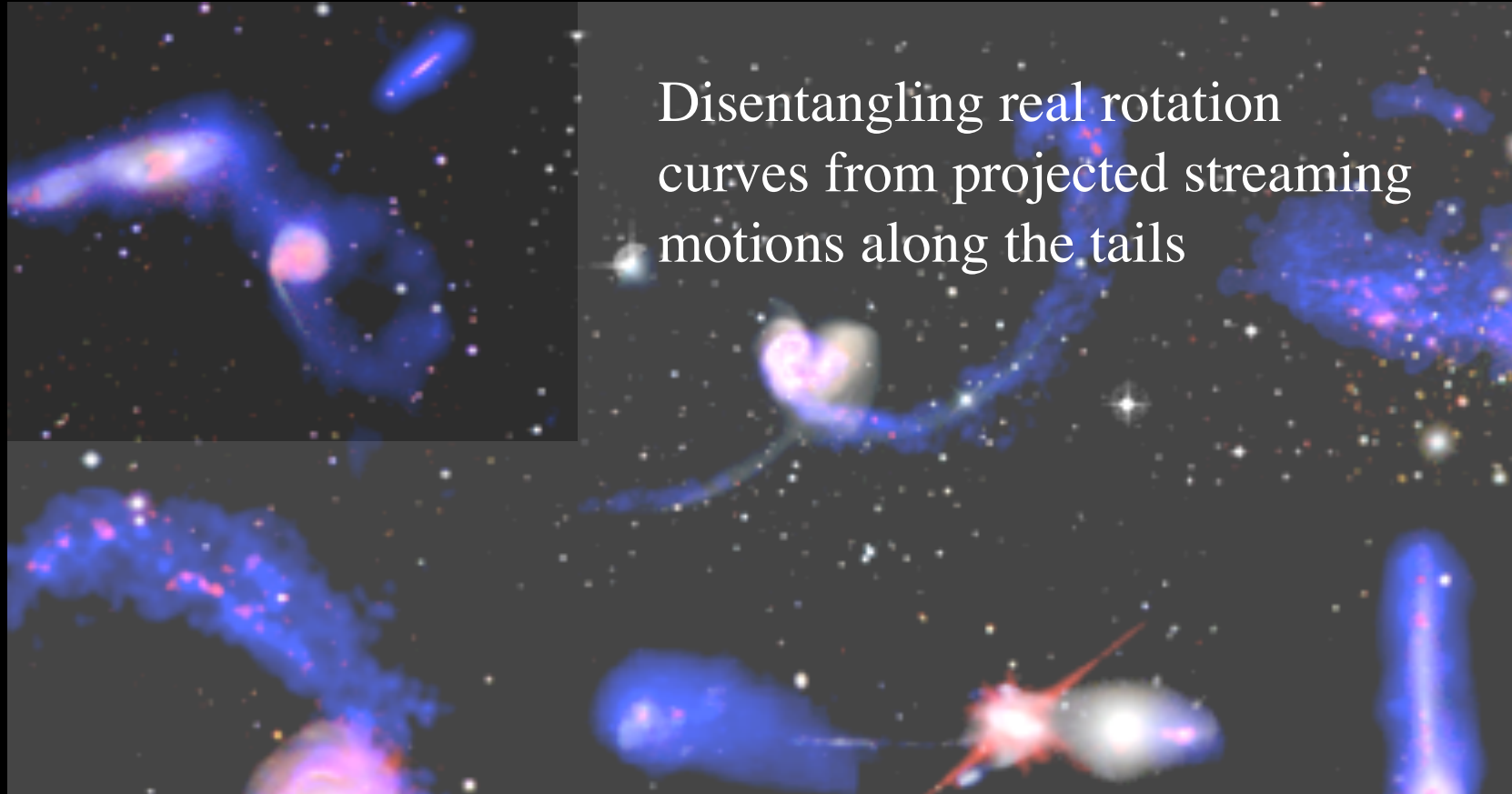
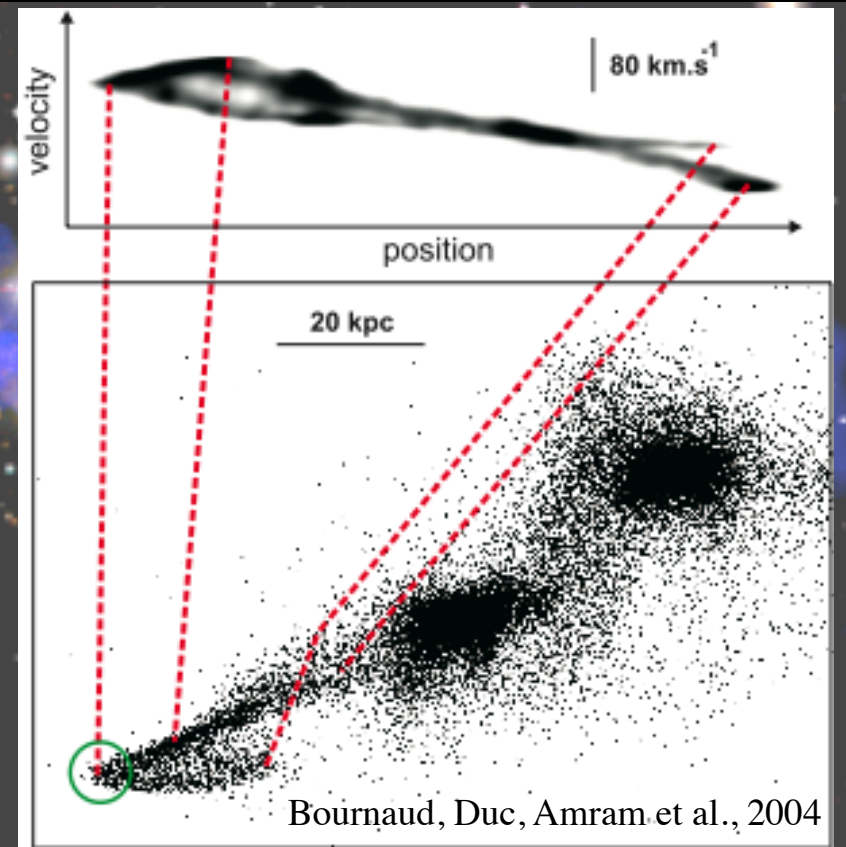


Bournaud et al., 2010



Dealing with projection effects

Disentangling real rotation curves from projected streaming motions along the tails



NGC 2992