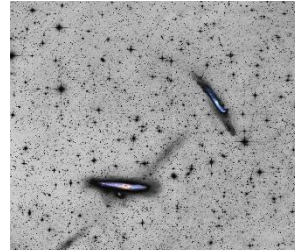
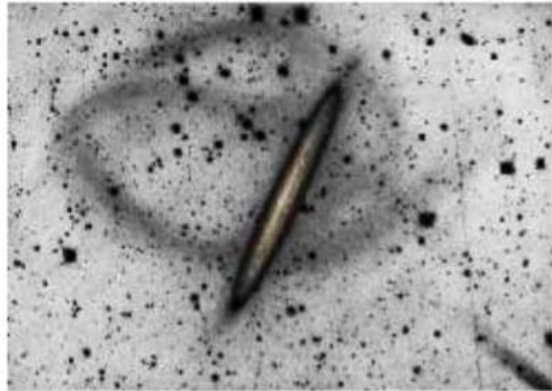


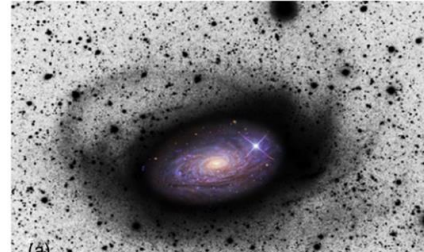
Streams as Cosmological Diagnostics

Gustavo Morales

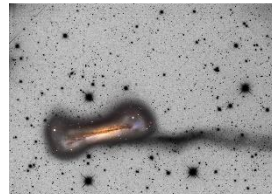
David Martínez-Delgado, Eva Grebel, Volker Springel



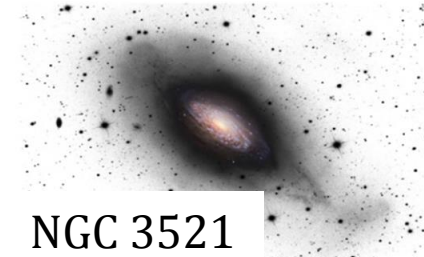
NGC 4631



NGC 5055 / M63



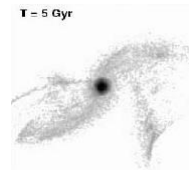
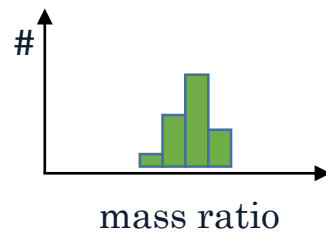
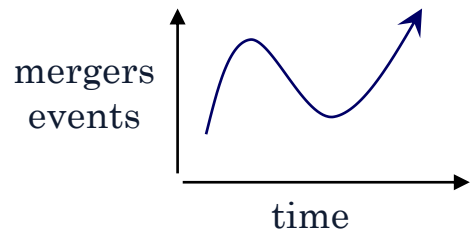
NGC 3628



NGC 3521

minor/minuscule merging

host-satellite mass ratio $\sim 1:100$
 $\mu_g \geq 27 \text{ mag/arcsec}^2$



merging orbit characterization

Stellar Tidal Streams as Cosmological Diagnostics

Ph.D. Thesis Project

Gustavo Morales, David Martínez-Delgado, Eva Grebel, Volker Springel
 Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg

Baryons at low densities: the stellar halos around galaxies @ ESO Garching, 23-27 February, 2015

I - BASICS

(A) WHAT

A **Stellar Tidal Stream (STS)** is an association of stars that once were part of a satellite that has now been torn apart and stretched out along its orbit by tidal forces. They have very low mass and low brightness.

host-satellite mass ratio $\sim 1:100$
 surface brightness $\sim 27 \text{ mag/arcsec}^2$

minor/minuscule merging

In general terms, all stars lost due to dynamical processes end up in the galactic tidal field:

Initial escape
 Violent relaxation
 3 body encounters
 Slow evaporation

Streams are a natural outcome of dynamical evolution in a tidal field

(B) WHY

In the context of local group cosmology, STSs are a useful tool for galaxy formation theory testing in more extreme conditions. We know that merging of halos (and the galaxies within them) is a key driver of galaxy evolution in the Λ CDM paradigm. All big galaxies should experience merging, including disk galaxies. But despite the importance of mergers, empirical constraints on how often they happen, what the distribution of merger mass ratios is, and merging orbit characterization, are poor.

(C) HOW

By using deep imaging of nearby galaxies from our own survey and the SDSS in combination with state-of-the-art simulations to assess what the incidence and role of minor mergers in nearby galaxies is.

Follow-up observations with 8m telescopes resolved stellar populations, globular clusters and dynamical streams, search for NGCs embedded in the streams.

N-body models, dynamical masses of streams, streamers, search for NGCs embedded in the streams (e.g. Johnston et al. 2008)

Comparison with LCDM model predictions (e.g. Cooper et al. 2006)

II - DATA

The **Stellar Tidal Stream Survey, STSS**

This project is part of the **STSS**. We plan to observe a volume completed sample of spiral galaxies up to 12 Mpc with amateur robotic telescopes (e.g. Martínez-Delgado et al. 2010).

Objective: to impose observational constraints on the rate and consequences of minor mergers in spiral galaxies of the local volume.

Galaxy	Constellation	Right Asc.	Declination	RA (h:m:s)	Dec (d:m:s)
NGC 3521	Andromeda	00:52:00	+41:30:00	00:52:00	+41:30:00
NGC 3628	Andromeda	00:55:00	+41:30:00	00:55:00	+41:30:00
NGC 4631	Andromeda	00:58:00	+41:30:00	00:58:00	+41:30:00
NGC 5055	Andromeda	01:00:00	+41:30:00	01:00:00	+41:30:00

Fig. 4 - Comparison of the STSS observations of NGC 4631 (Martínez-Delgado et al. 2010) with the MagCam@CIT 1.5-meter telescope (Díaz et al. 2010). The surface brightness limit of both images is similar and as faint as 28 mag/arcsec² in the ground (Díaz et al. 2010).

III - PRELIMINARY RESULTS

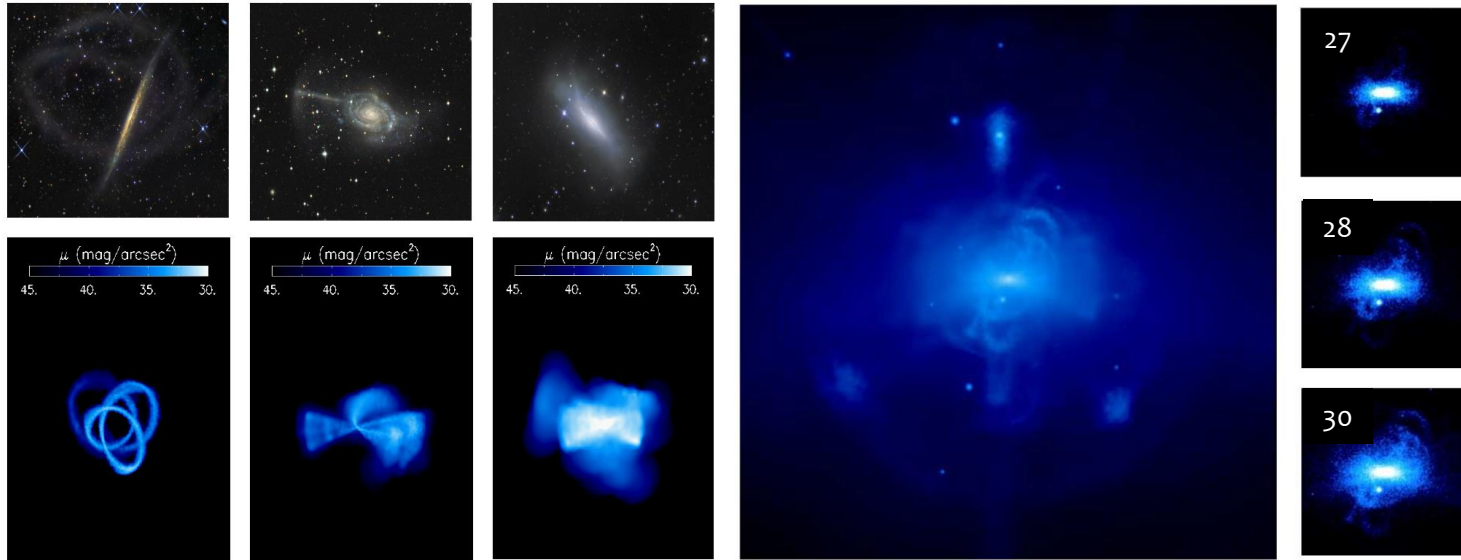
Fig. 5 - Some tidal streams already observed in this project. Our STSS data revealed that many spiral galaxies in the Local Universe contain significant numbers of gigantic stellar structures that resemble the features expected from hierarchical formation.

Fig. 6 - Expected halo streams around a Milky Way-like galaxy from a cosmological simulation (Johnston et al. 2008). The Figure 150 kpc by side shows an external perspective of one realization of a simulation within the hierarchical framework, with streams, resulting from tidally disrupted satellites for typical accretion histories of Milky Way-type galaxies. Theoretical predictions for the detectable tidal features for the same halo model but assuming three different surface brightness (SB) limit detection limits: A) 30, B) 29 and C) 30 mag/arcsec². Each snapshot at the right is 100 kpc by side, and correspond to the typical halo area covered by our survey in each target. No discernible sub-structure is expected for surveys with SB limits brighter than $>35 \text{ mag/arcsec}^2$ (e.g. POSS1 and SDSS). This result also shows that the number of tidal features visible on the outskirts of spirals depends dramatically on the SB limit of the observations.

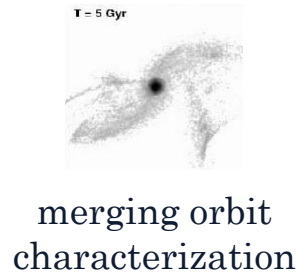
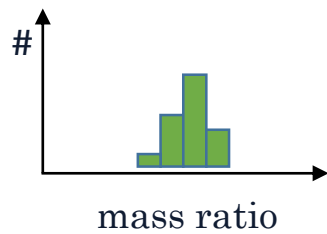
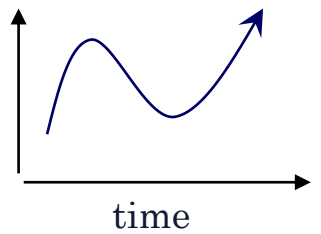
Streams as Cosmological Diagnostics

Gustavo Morales

David Martínez-Delgado, Eva Grebel, Volker Springel



mergers events



Stellar Tidal Streams as Cosmological Diagnostics

Ph.D. Thesis Project
Gustavo Morales, David Martínez-Delgado, Eva Grebel, Volker Springel
Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg
Baryons at low densities: the stellar halos around galaxies @ ESO Garching, 23-27 February, 2015

(A) WHAT

A **Stellar Tidal Stream (STS)** is an association of stars that once were part of a satellite that has now been torn apart and stretched out along its orbit by tidal forces. They have very low mass and low brightness.

host-satellite mass ratio ~ 1:100
surface brightness ~ 37 mag/arcsec²

minor/major axis merging

In general terms, all stars lost due to dynamical processes end up in the galactic tidal field:

Initial escape → Violent relaxation → 3-body encounters → Slow evaporation → **galactic tidal field**

Streams are a natural outcome of dynamical evolution in a tidal field.

(B) WHY

In the context of local group cosmology, **STSs** are a useful tool for galaxy formation theory testing in more extreme conditions. We know that merging of halos (and the galaxies within them) is a key driver of galaxy evolution in the Λ CDM paradigm. All big galaxies should experience merging, including disk galaxies. But despite the importance of mergers, empirical constraints on how often they happen, what the distribution of merger mass ratios is, and merging orbit characterization, are **poor**.

(C) HOW

By using **deep imaging** of nearby galaxies from our own survey and the **SDSS** in combination with state-of-the-art simulations to assess what the incidence and role of **minor mergers** in nearby galaxies is.

Follow-up observations with 8m telescopes resolved stellar populations, globular clusters and dynamical streams search for STSs embedded in the primary galaxy.

Robust models, dynamical masses of streams, and the search for STSs embedded in the primary galaxy (e.g. Johnston et al. 2008)

Comparison with Λ CDM model predictions (e.g. Cooper et al. 2006)

I - BASICS

II - DATA

The Stellar Tidal Stream Survey, STSS

This project is part of the **STSS**. We plan to observe a volume completed sample of spiral galaxies up to 12 Mpc with amateur robotic telescopes (e.g. Martínez-Delgado et al. 2010).

Galaxy	RA (J2000)	Dec (J2000)	Redshift	Distance (Mpc)	Galaxy Type
NGC 5917	10:00:00	+00:00:00	0.01	100	Spiral
NGC 4631	10:00:00	+00:00:00	0.01	100	Spiral
NGC 5055 / M63	10:00:00	+00:00:00	0.01	100	Spiral
NGC 5236 / M83	10:00:00	+00:00:00	0.01	100	Spiral
NGC 3521	10:00:00	+00:00:00	0.01	100	Spiral
NGC 3628	10:00:00	+00:00:00	0.01	100	Spiral

Objective: to impose observational constraints on the rate and consequences of minor mergers in spiral galaxies of the local volume.

III - PRELIMINARY RESULTS

Some tidal streams already observed in this project. Our STSS data revealed that many spiral galaxies in the Local Universe contain significant numbers of gigantic stellar structures that resemble the features expected from hierarchical formation.

Fig. 4 - Comparison of the STSS observations of NGC 5917 (Martínez-Delgado et al. 2010) with the Magellan-GEMINI 3.6-meter telescope (Díaz et al. 2010). The surface brightness limit of both images is similar and as faint as 28 mag/arcsec² in the ground (Díaz et al. 2010).

Fig. 5 - Some tidal streams already observed in this project. Our STSS data revealed that many spiral galaxies in the Local Universe contain significant numbers of gigantic stellar structures that resemble the features expected from hierarchical formation.

Fig. 6 - Expected halo streams around a Milky Way-like galaxy from a cosmological simulation (Johnston et al. 2008). The figure shows an external perspective of one realization of a simulation within the hierarchical framework, with streams, resulting from tidally disrupted satellites for typical accretion histories of Milky Way-type galaxies. Theoretical predictions for the detectable tidal features for the same halo model, but assuming three different surface brightness (SB) limit detection limits: A) 30, B) 35 and C) 30 mag/arcsec². Each snapshot at the right is 100 kpc by side, and correspond to the typical halo area covered by our survey in each target. No discernible sub-structure is expected for surveys with SB limits brighter than ~35 mag/arcsec² (e.g. POSS1 and SDSS). This result also shows that the number of tidal features visible on the outskirts of spirals depends dramatically on the SB limit of the observations.