High-resolution N-body Simulations of Galactic Cannibalism

The Magellanic Stream

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Abstract

Through the investigation of the closest obvious group of interacting galaxies, the Magellanic Clouds and the Milky Way Galaxy, we hope to understand the process of hierarchical clustering in detail.
1. Introduction

1.1. Introduction – Magellanic System

Magellanic System is Large and Small Magellanic Clouds and the spectacular gas streams – MS and LAF.

Close example of Galactic Cannibalism – an example of Hierarchical Clustering.

Putman et al. (1998)
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Favourable position ⇒ Best chance of untangling physics, as can resolve individual stars, proper motions and distances. Not a stellar stream; shaped by hydrodynamical & tidal forces.
1.2. Motivation

Best laboratory for study of

- Formation of tidal streams
- Effect of interaction and SNe feedback on SF in cannibalised dwarfs.

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First, this study allows us to hunt down allowable parameters

We investigate how pure tidal forces influence stream, and find what the formation process of Magellanic Stream is
2. N-body simulation of SMC and Magellanic Stream

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Use **GCD+**: 3D vector/parallel tree N-body/SPH code: Includes hydrodynamics, radiative cooling, star formation, SNe feedback, metal enrichment.
3. Modelling Strategy

A step-by-step model construction

A: N-body model of SMC

N-body is fast: Parameter search required over many undetermined quantities
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A step-by-step model construction

A: N-body model of SMC
   N-body is fast: Parameter search required over many undetermined quantities

Almost completed — Connors et al. 2004 already published

B: Include hydrodynamics/Star Formation/Chemodynamical evolution
   Based on best model determined in A, find star formation history within SMC
   SNe feedback is most complicated and poorly understood
   SMC is good laboratory for such study
4. Parameter survey

Best model determined by both spatial and kinematical agreement with:
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Survey performed in N-dimensional parameter space:

- *radius* of SMC disk
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Survey performed in N-dimensional parameter space:

- **radius** of SMC disk
- **mass** of LMC (orbit changes)
- **geometrical angle** angle SMC disk
- mass of SMC disk / mass of SMC halo
5. **Best model: HI column density**

Quantitative comparison with observation: HIPASS data cube courtesy of Mary Putman; added Northern Extension
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Observation ⇔ Simulation (ZEA coordinates)

Overall features of LAF and MS reproduced
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MS and LAF density/length/angle are not perfect
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![Graphs showing quantitative comparison between observation and simulation](image)

**Observation** ⇔ **Simulation** (ZEA coordinates)

Overall features of LAF and MS reproduced

For the first time, actual **quantitative comparisons** reveal problems:

MS and LAF density/length/angle are not perfect

Adding drag (ram pressure from Galaxy halo) may fix these.
6. Best model: Kinematics ("$v_{Sub}$")

800 km s$^{-1}$ velocity LSR range: Too hard to see any small scale differences

Subtract trend from observational data equally Velocity in

$V_{SUB} = V_{GSR} - V_{MAG}$.
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**Subtract trend** from observational data equally. Velocity in $V_{SUB} = V_{GSR} - V_{MAG}$:

![Observation](image1.png) ![Simulation](image2.png)

Observation
Mostly consistent, except for residuals around LAF
7. **Best model:** Kinematics (\(v_{\text{LSR}} \text{ vs } l_{\text{Mag}}\))

Another projection:

**Observation**

Simulation: Clear bifurcation in \(v_{\text{LSR}} \text{ vs } l_{\text{Mag}}\) - not so clear in low resolution simulations

Observations: Difficult to tell: Christian Br"uns has same data with different reduction technique
8. Hydro/Star formation

No stars observed in MS and LAF
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Features similar to N-body
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More analysis in progress
9. Conclusions

First ever fully quantitative rather than qualitative comparison between detailed observations and simulation
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Extensive parameter survey found best model (radius, $M_{LMC}$, and angle important)
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N-body parameter survey nearing completion, leads to full gas treatment
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Parameter survey
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Magellanic Stream in HI
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Conclusions
Two theories - tidal and ram pressure stripping
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Noguchi 1999; Yoshizawa & Noguchi 2003

Gardiner Noguchi 1996 (re-rendered)
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LAF $\Rightarrow$ Ram pressure not quite dead yet

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LAF $\Rightarrow$ Ram pressure not quite dead yet:
Mastropietro et al. 2004

Gardiner Noguchi 1996 (re-rendered)
Movie of low res MS
Full sky image of the HVCs.
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Best model: . . .
Hydro/Star formation
Conclusions
Center of Mass
SMC orbit
LMC orbit
disk particles
First, the radius (5.5 kpc – fiducial)
First, the radius (4.5 kpc – small)
First, the radius (3.0 kpc – smaller)
First, the radius (5.5 kpc – fiducial again)
First, the radius (7.0 kpc – larger)
Then, the mass of LMC \((2 \times 10^{10} M_\odot \text{ – fiducial})\)
Then, the mass of LMC \( \left( 1 \times 10^{10} M_\odot \right) \)
Then, angle of SMC disk – 2 degrees freedom (45, 210° – fiducial)
Then, the angle of SMC \((30, 210° – \text{only } 15° \text{ different})\)