Are the Magellanic Clouds on Their First Passage about the Milky Way ?

Speaker: Yan Liang

Date: 2022-3-11

Outline

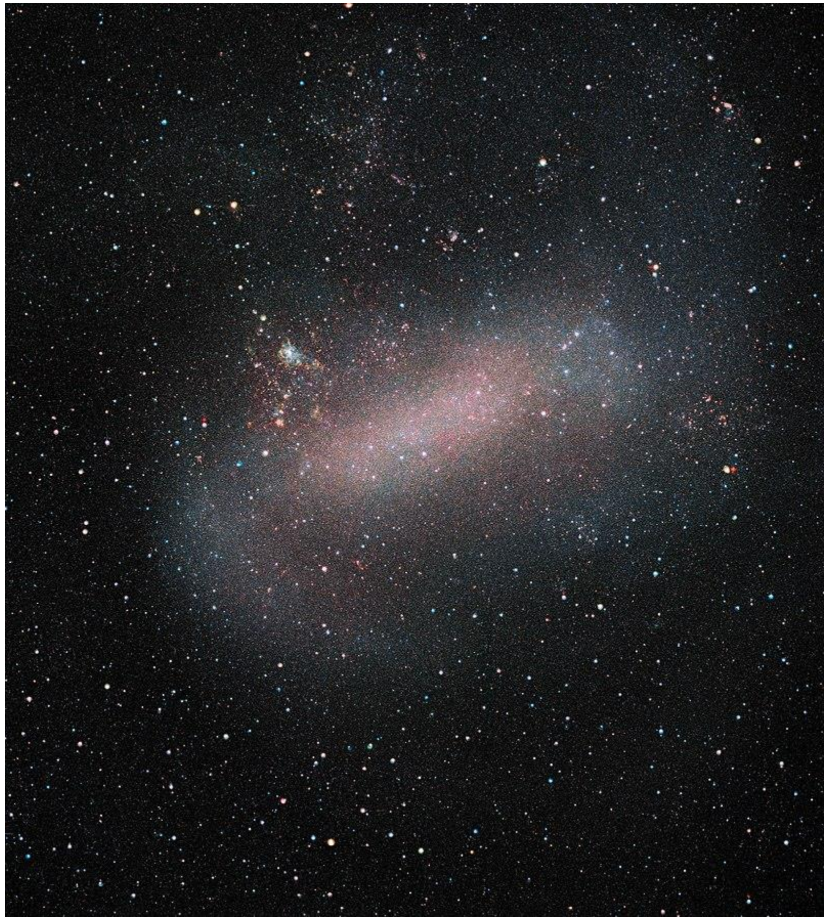
- An Overview of the Magellanic Clouds (MCs)
- The Multiple Passages Scenario
- The First Passage Scenario
- Why Do We Need the First Passage Scenario
- Comments

Overview of the Magellanic Clouds

- The Large and Small Magellanic Clouds (LMC/SMC) are dwarf irregular galaxies in the southern hemisphere.
- Both are satellite galaxies of the MW.
- LMC is located in Dorado
- SMC is located in Tucana
- They have been known since ancient times, but named from Ferdinand Magellan who observed them on his circumnavigation in 1519–1522

Overview of the LMC

- The distance from the Galactic center: $50 \pm 1\ kpc$
- The stellar mass: $3 \times 10^9\ M_{sun}$
- The halo mass: $1.7 \times 10^{10} M_{sun}$
- The HI gas mass: $4.4 \times 10^8 M_{sun}$
- One-armed spiral with off-centered bar



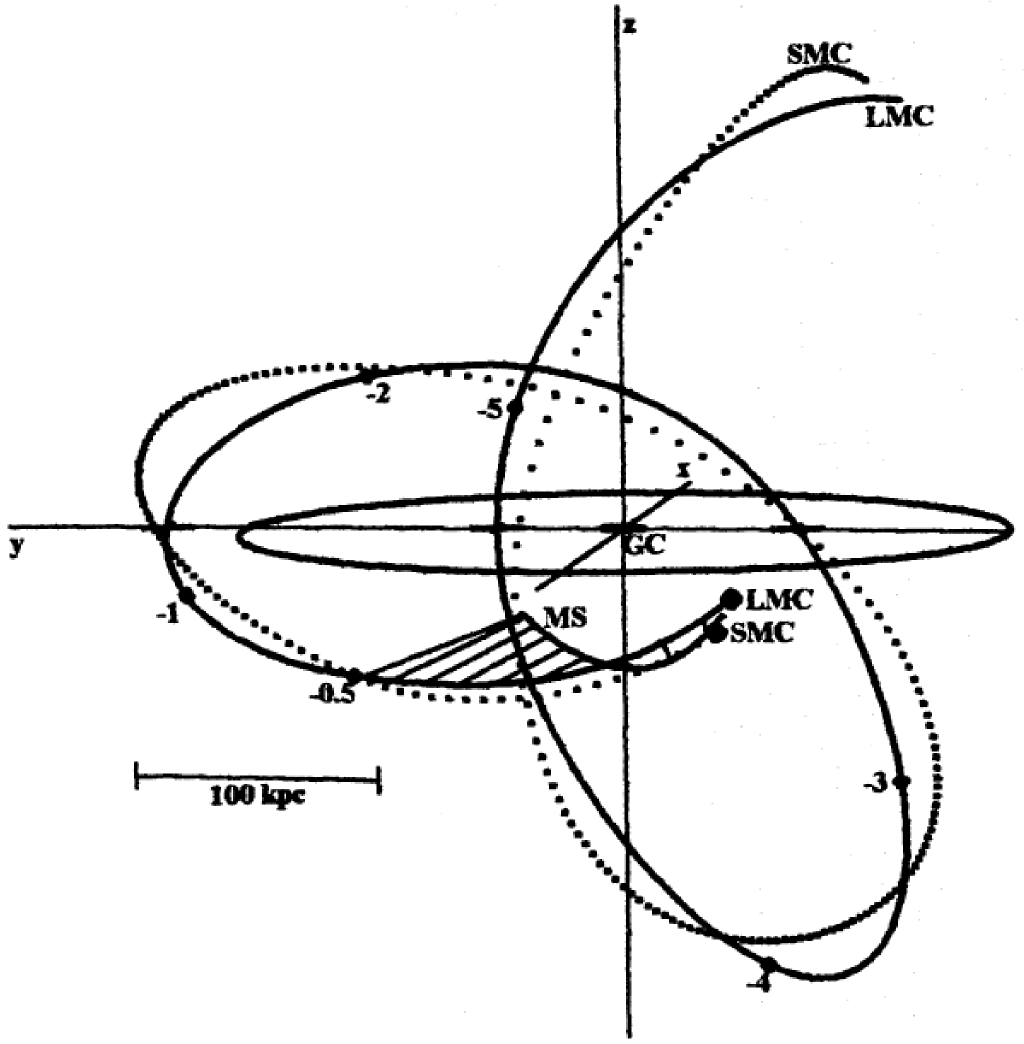
Overview of the SMC

- The distance from the Galactic center: $61 \pm 1\ kpc$
- The stellar mass: $3 \times 10^8\ M_{sun}$
- The halo mass: $2.4 \times 10^9 M_{sun}$
- The HI gas mass: $4.0 \times 10^8 M_{sun}$
- Irregular and asymmetric due to the tidal interaction with the LMC

What is the multiple or first passage scenario?

The Multiple Passage Scenario:

- MCs follow a gravitationally bound orbit around the MW and have been staying within the virial radius of the MW for a several orbital periods.

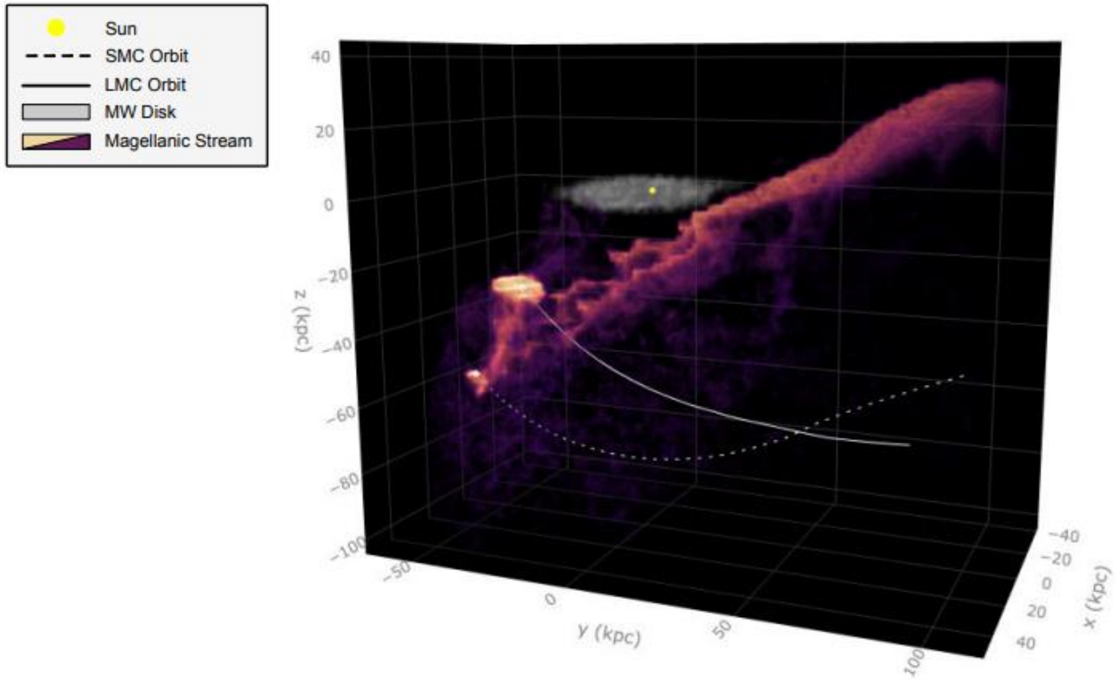


What is the first or multiple passage scenario?

The First Passage Scenario:

- MCs are just past their first pericentric way to the MW, and has not completed a single period of the orbit (if the period exists).

- MCs may be the interlopers that formed in a more remote region of the Local Group, and first entered the virial radius of the MW 1~4 Gyr ago



The proper motion measurement of MCs

Summary of LMC Orbital Parameters Adopted in Previous Studies

Work	3D v (x,y,z) (km/s)[a]	$\|v\|$ (km/s)	v_{tan} (km/s)	v_{rad} (km/s)	r (x,y,z) (kpc)	T (Gyr) [b]	Peri (kpc)	Apo (kpc)
MF80	(233.7,-13.1,252.4)[c]	344	340	92	(42.9,-2.4,-28.3)	1.5	50	110
GSF94, GN96	(-5,-226, 194)[c]	297	287	82	(-1.0,-40.8,-26.8)	1.5	45	120
HR94	(-10.06,-287.09,229.73)[c]	367.83	351.81	107.37	(-0.85,-40.85,-27.95)	2.5	46.3	180
vdM02	(-56 ± 36, -219 ± 23, 186 ± 35)[d]	293 ± 39	281 ± 41	84 ± 7	(-0.8, -41.5, -26.9)	2	45	110
M05[e]	(-4.3,-182.45,169.8)[d]	249.3	237.9	74.4	(0,-43.9,-25.04)	2	45	115
K1 Mean	(-86 ± 12, -268 ± 11, 252 ± 16)[d]	378 ±18	367 ± 18	89 ± 4	(-0.8,-41.5,-26.9)	3	50	220
K2 Fig. 12	(-91, -250, 220)[d]	345	333	92	(-0.8,-41.5,-26.9)	2	50	150

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Assuming gravitational potential of the MW

The proper motion measurement of MCs

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Assuming gravitational potential of the MW ↓ Integrating backwards in time

The proper motion measurement of MCs

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Orbital History of the MCs

The proper motion measurement of MCs

ES

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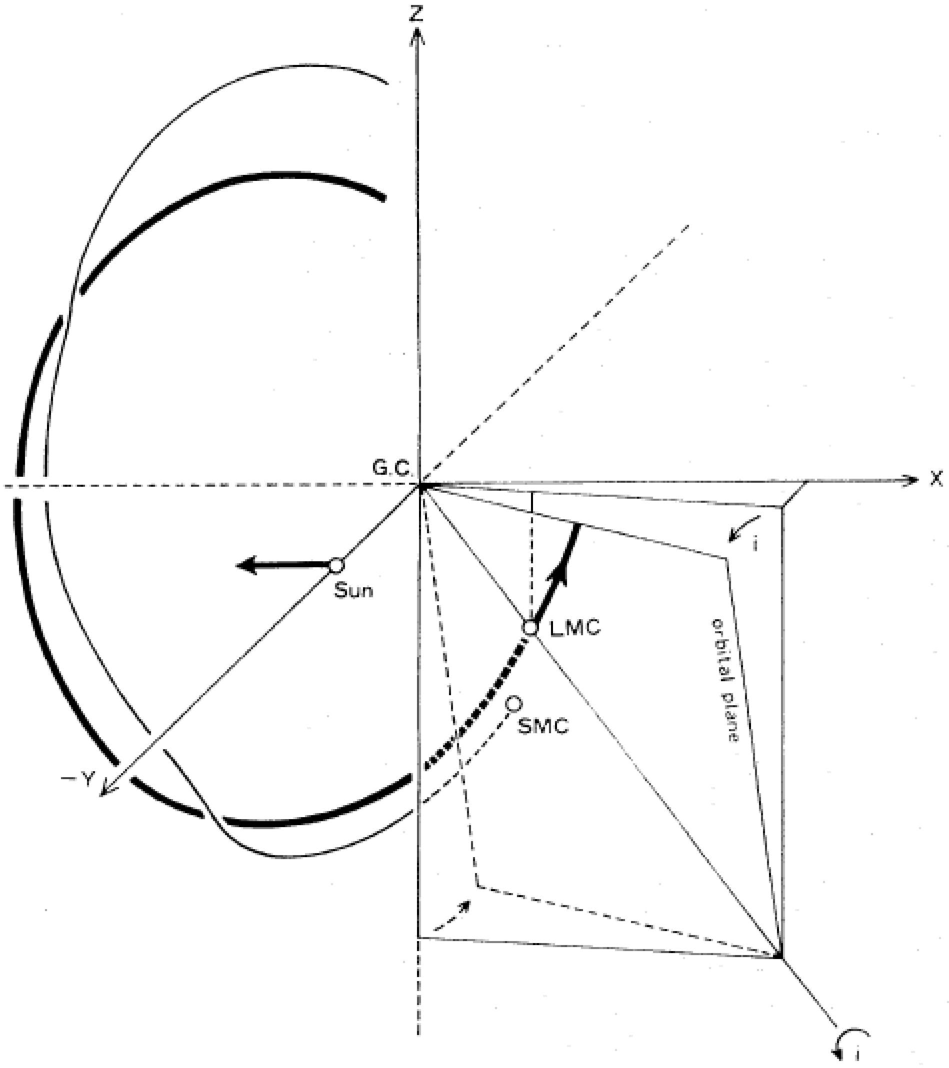

Assuming gravita … in time

Multiple Passages Scenario

Gravitational Potential of the MW

- Murai T. & Fujimoto M. 1980 : Isothermal Sphere
- Gardiner L. T. et al. 1994 : Isothermal Sphere
- Heller P. & Rohlfs K. 1994 : Modified Isothermal Sphere
- Mastropietro C. et al. 2005 : Bulge + Disk + Hot Gas + DM halo

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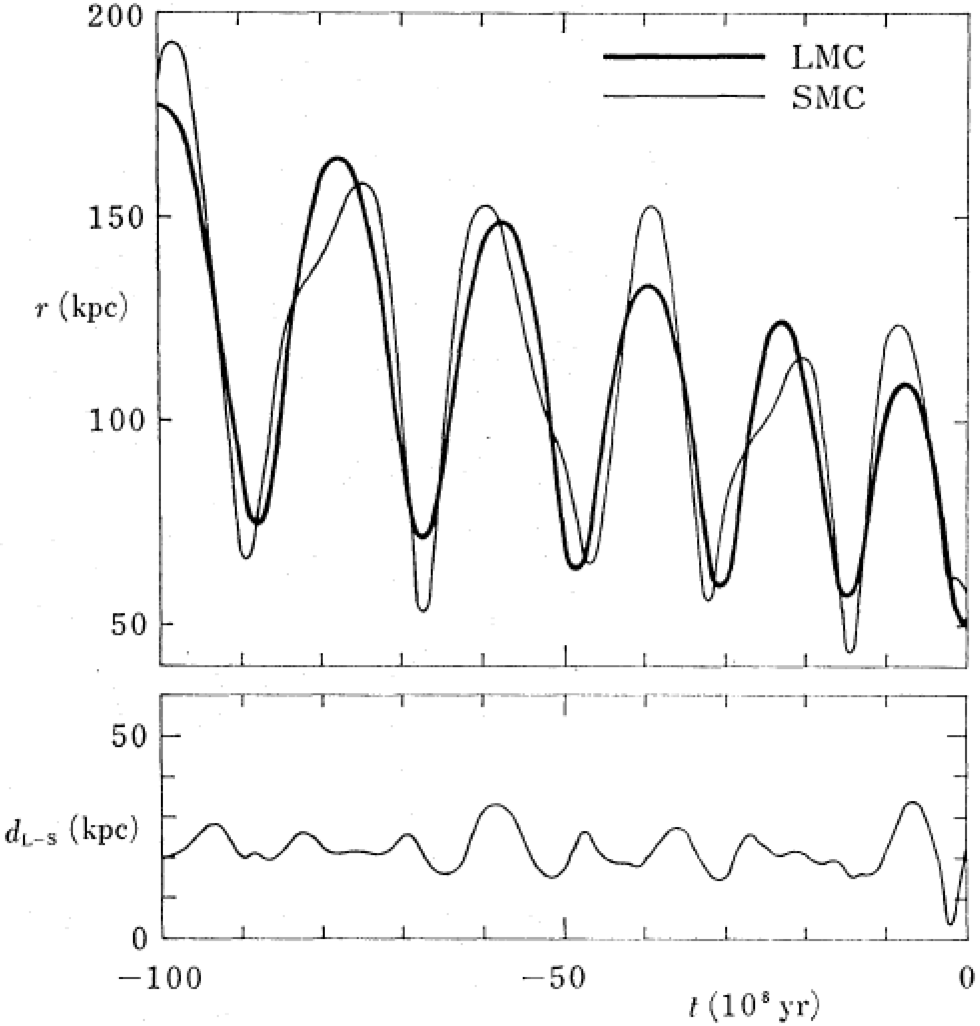
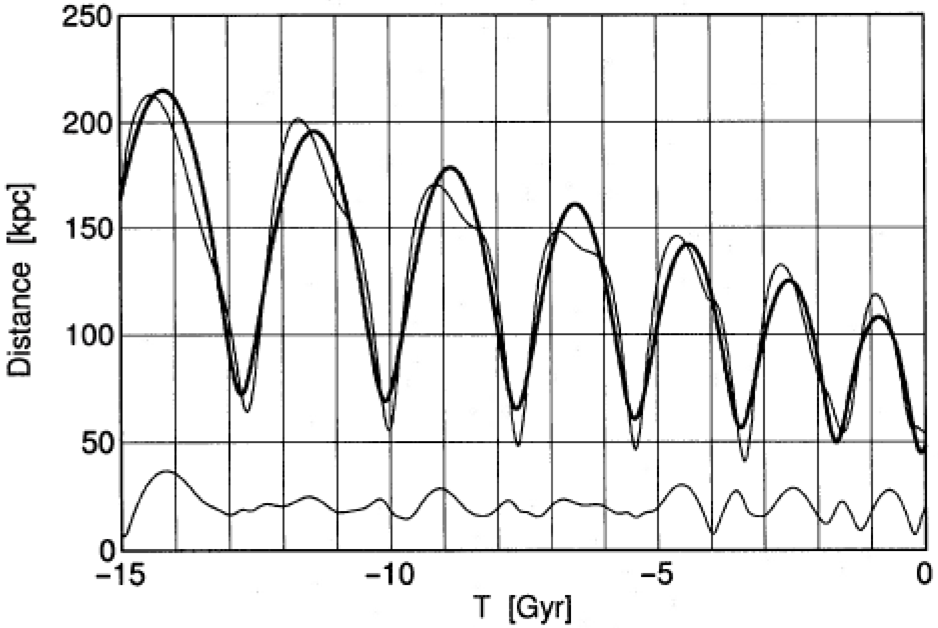
All of these works considered the effect of the dynamical friction & the interaction of the two clouds

Orbital History of the MCs in the Multiple Passage Scenario

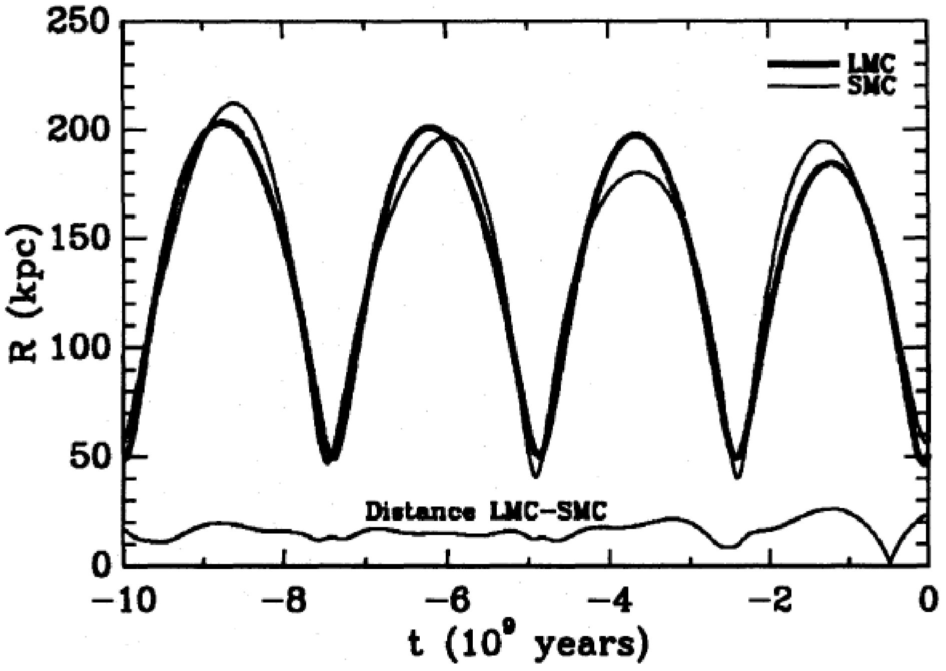


Murai T. & Fujimoto M. 1980



Gardiner L. T. et al. 1994

Orbital History of the MCs in the Multiple Passage Scenario



Heller P. & Rohlfs K. 1994

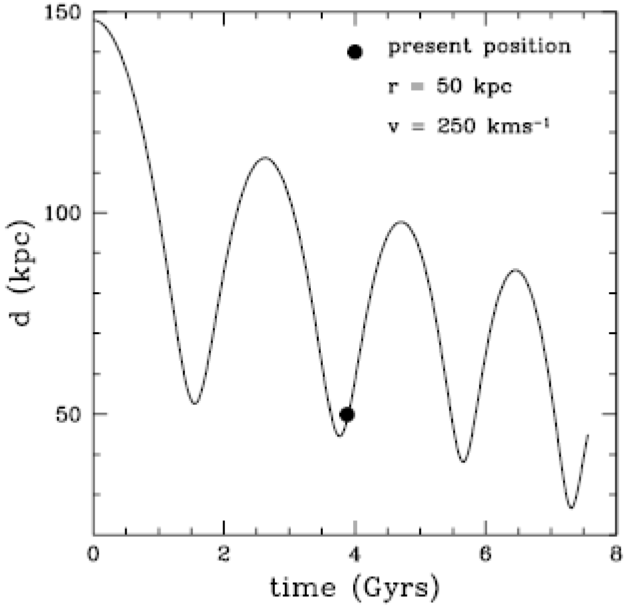
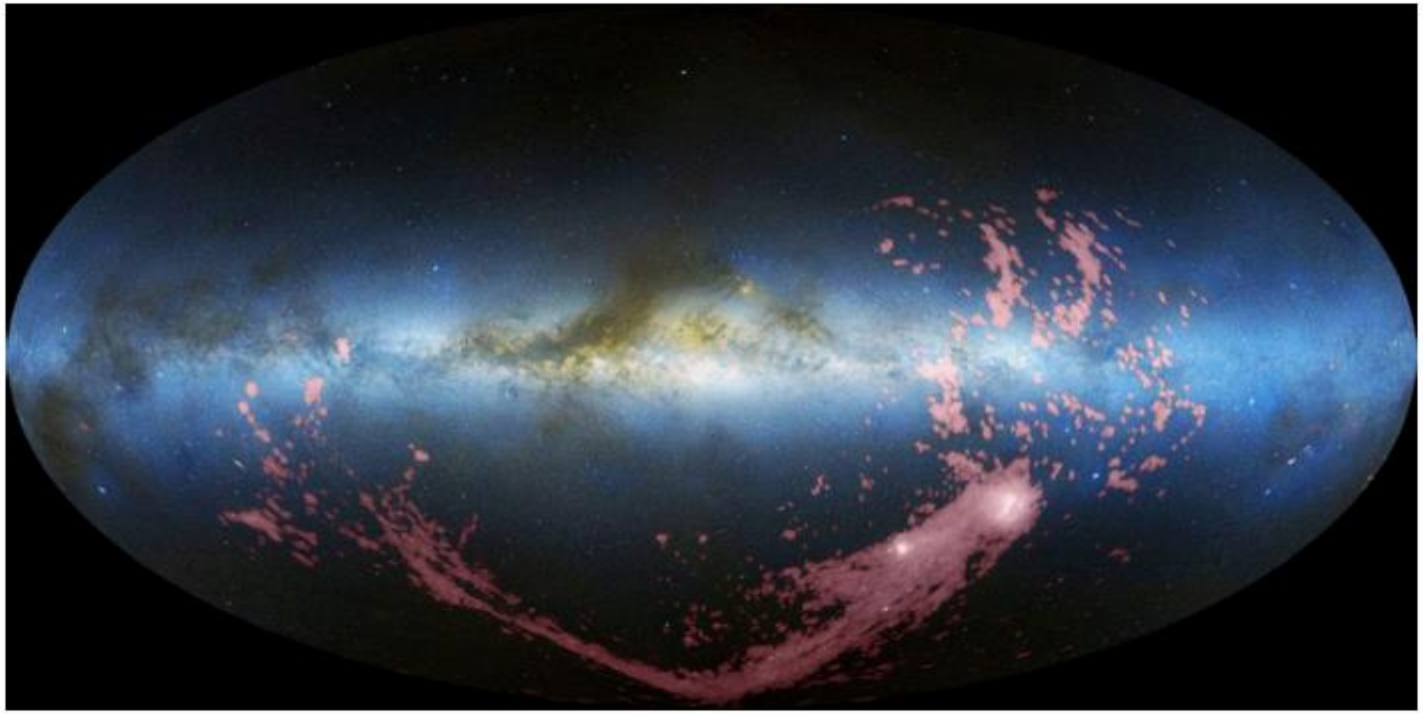


Figure 5. Orbital separation for the MW – LMC system

Mastropietro C. et al. 2005

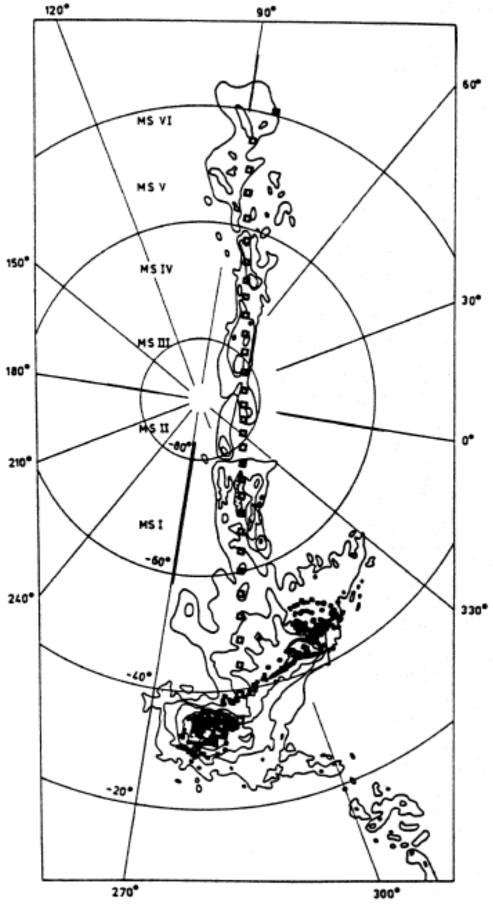
Constraint from the Magellanic Stream



The Magellanic Stream (MS), an extended tail of neutral and ionized gas trailing the Magellanic Clouds in their orbit around the Milky Way (MW)

Constraint from the Magellanic Stream

- Since the Magellanic Stream is the gas torn out from MCs by tidal effect or the ram pressure stripping when the MCs orbit through the gaseous halo of the MW, many researchers think that the MS can help trace the recent orbit of the MCs



Heller P. & Rohlfs K. 1994

The First Passage Scenario

The Astrophysical Journal, 638:772–785, 2006 February 20

THE PROPER MOTION OF THE LARGE MAGELLANIC CLOUD USING *HST*

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ABSTRACT

We present a measurement of the systemic proper motion of the Large Magellanic Cloud (LMC) from astrometry with the High Resolution Camera (HRC) of the Advanced Camera for Surveys (ACS) on the *Hubble Space Telescope* (*HST*). We observed LMC fields centered on 21 background QSOs that were discovered from their optical variability in the MACHO database. The QSOs are distributed homogeneously behind the central few degrees of the LMC. With two epochs of HRC data and a ~2 yr baseline, we determine the proper motion of the LMC to better than 5% accuracy: $\mu_W = -2.03 \pm 0.08$ mas yr^{-1}, and $\mu_N = 0.44 \pm 0.05$ mas yr^{-1}. This is the most accurate proper-motion measurement for any Milky Way satellite thus far. When combined with H I data from the Magellanic Stream, this should provide new constraints on both the mass distribution of the Galactic halo and models of the Stream.
Subject heading: Magellanic Clouds

The First Passage Scenario

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NITYA KALLIVAYALIL

SUMMARY OF LMC ORBITAL PARAMETERS ADOPTED IN PREVIOUS STUDIES

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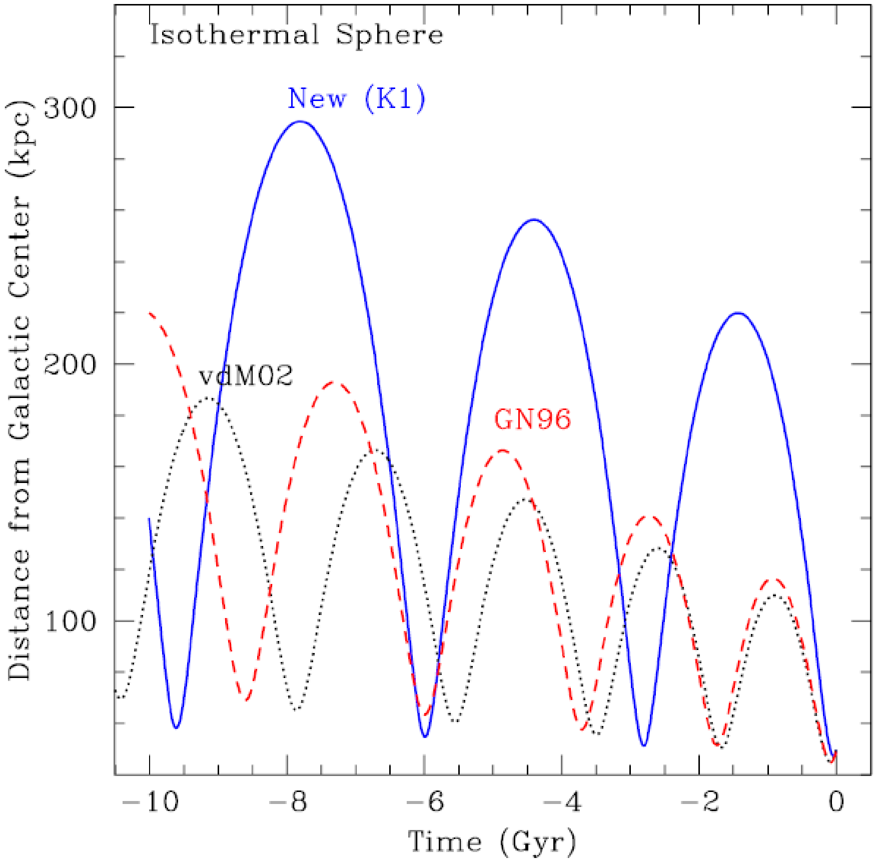
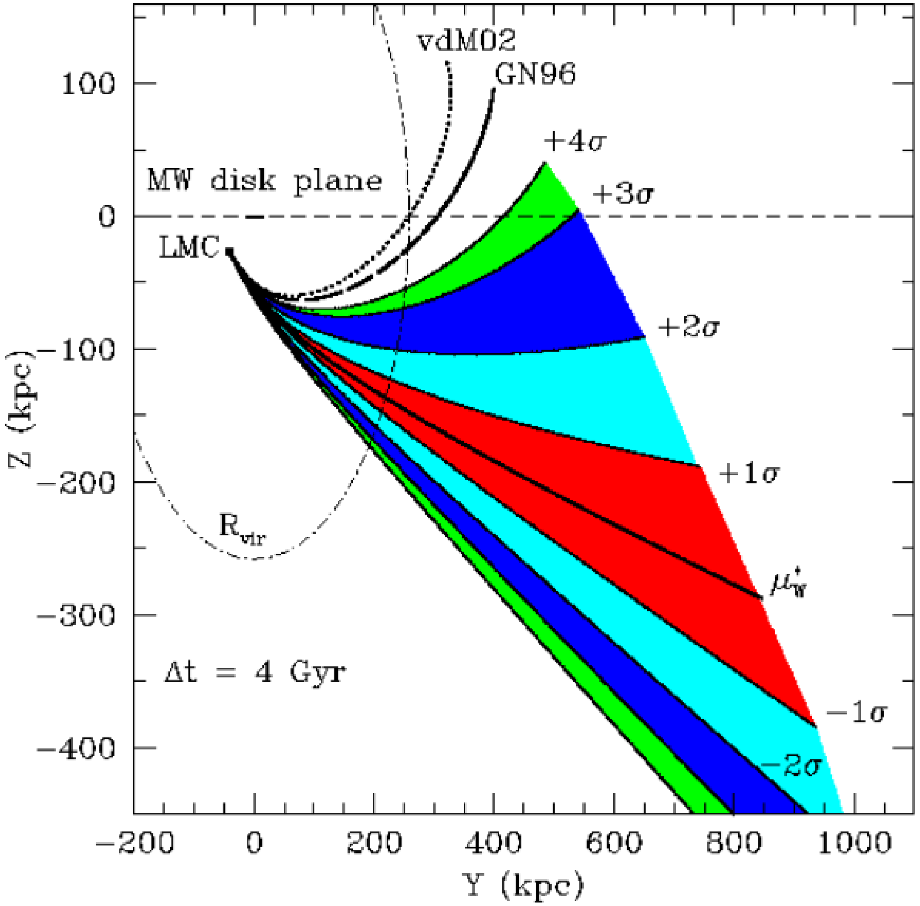


- If we still choose the isothermal sphere model for the new data, the orbit is periodic and the apogalacticon is about 300kpc.
- During the Hubble time, we have at least three periods (multi-passage).

The First Passage Scenario

Bulge : Hernquist Profile
Disk : Exponential Disk
DM halo : NFW Profile after Adiabatic Contraction
Hot Gas : Hydrostatic Equilibrium with the DM
Dynamical Friction: Chandrasekhar Formula

The First Passage Scenario



Possible Orbits of Recent 4Gyr

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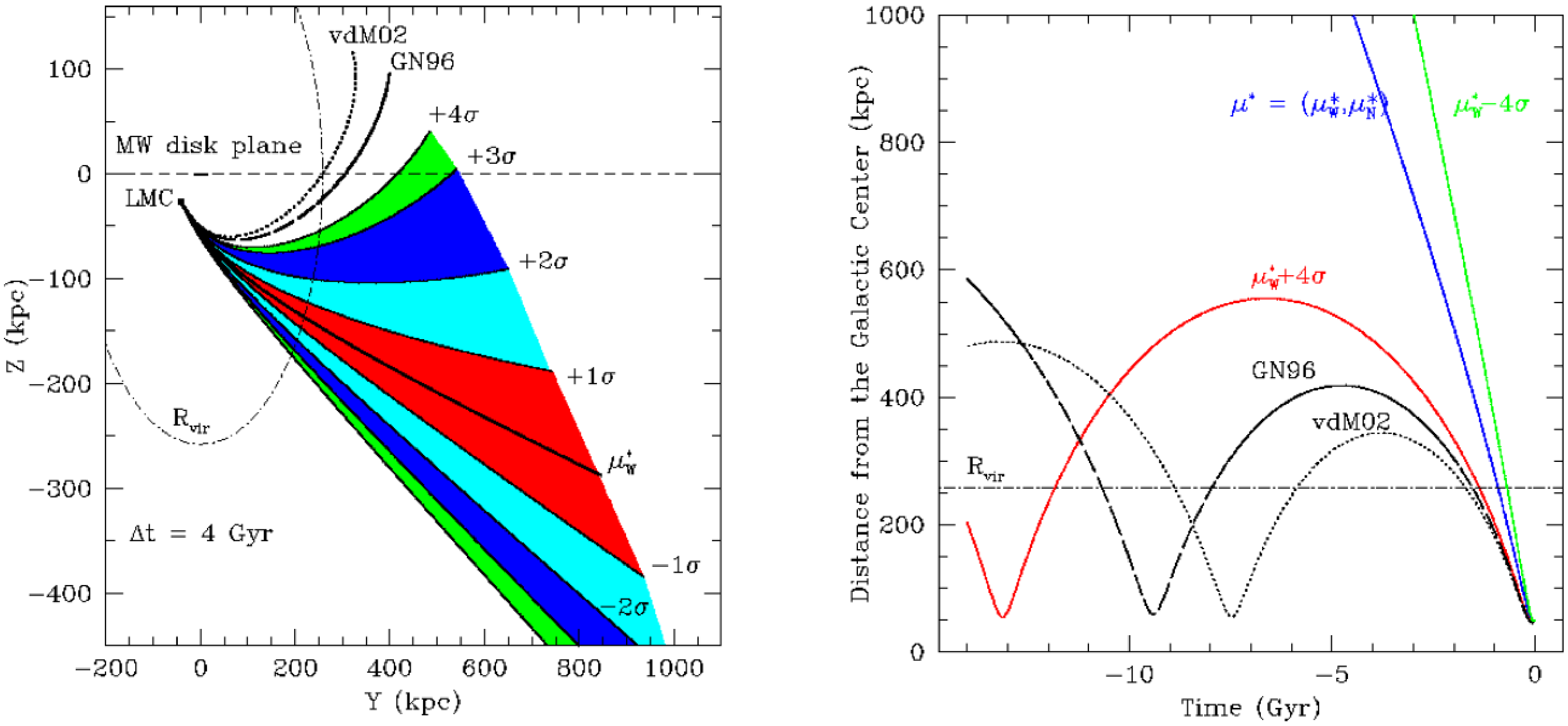
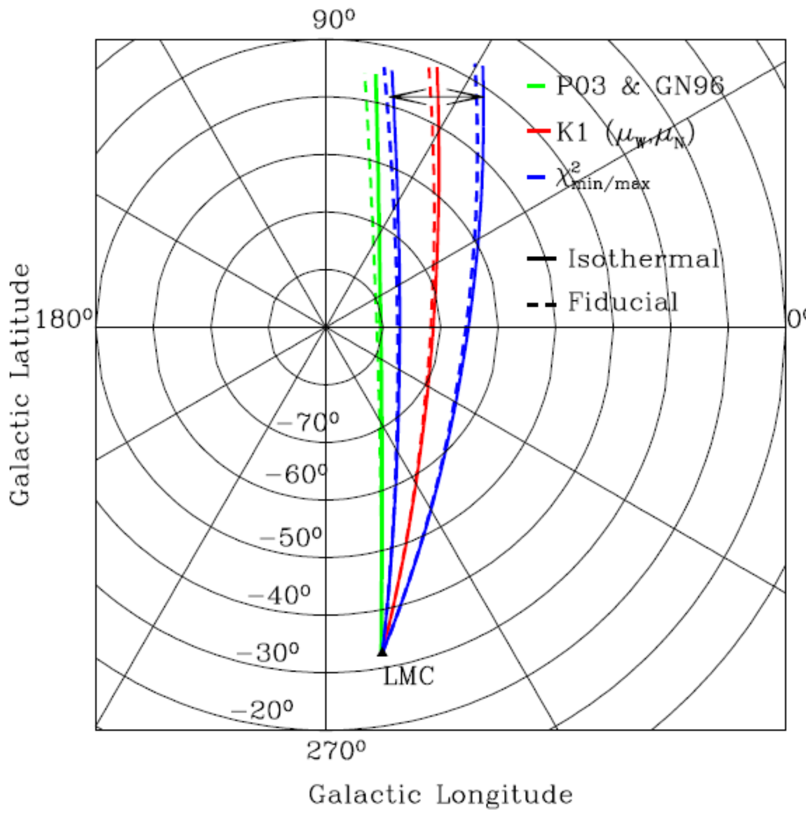
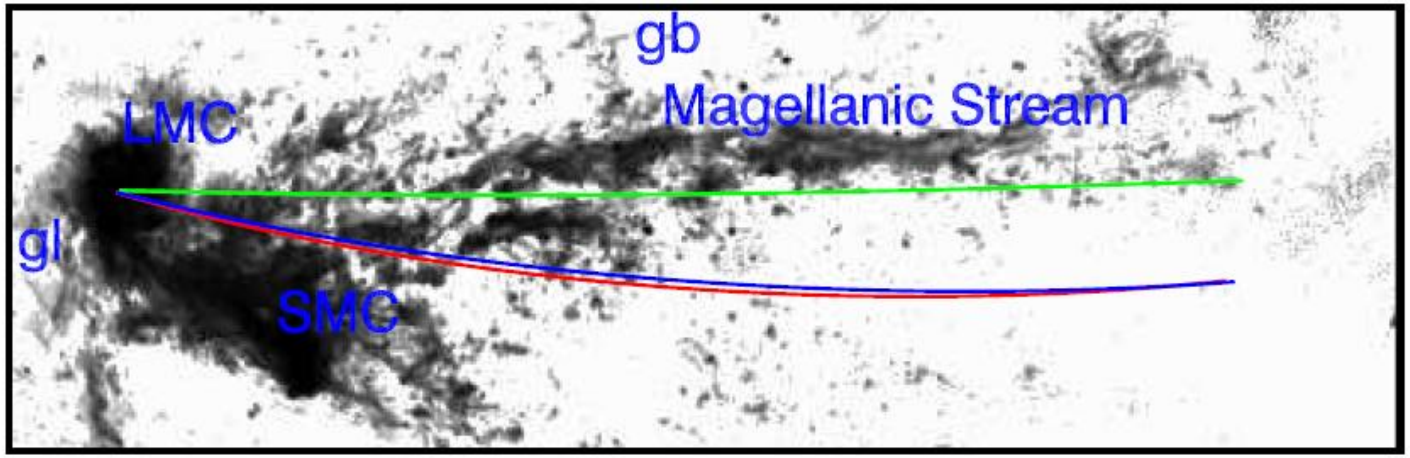
The First Passage Scenario



Besla G. et al. 2007

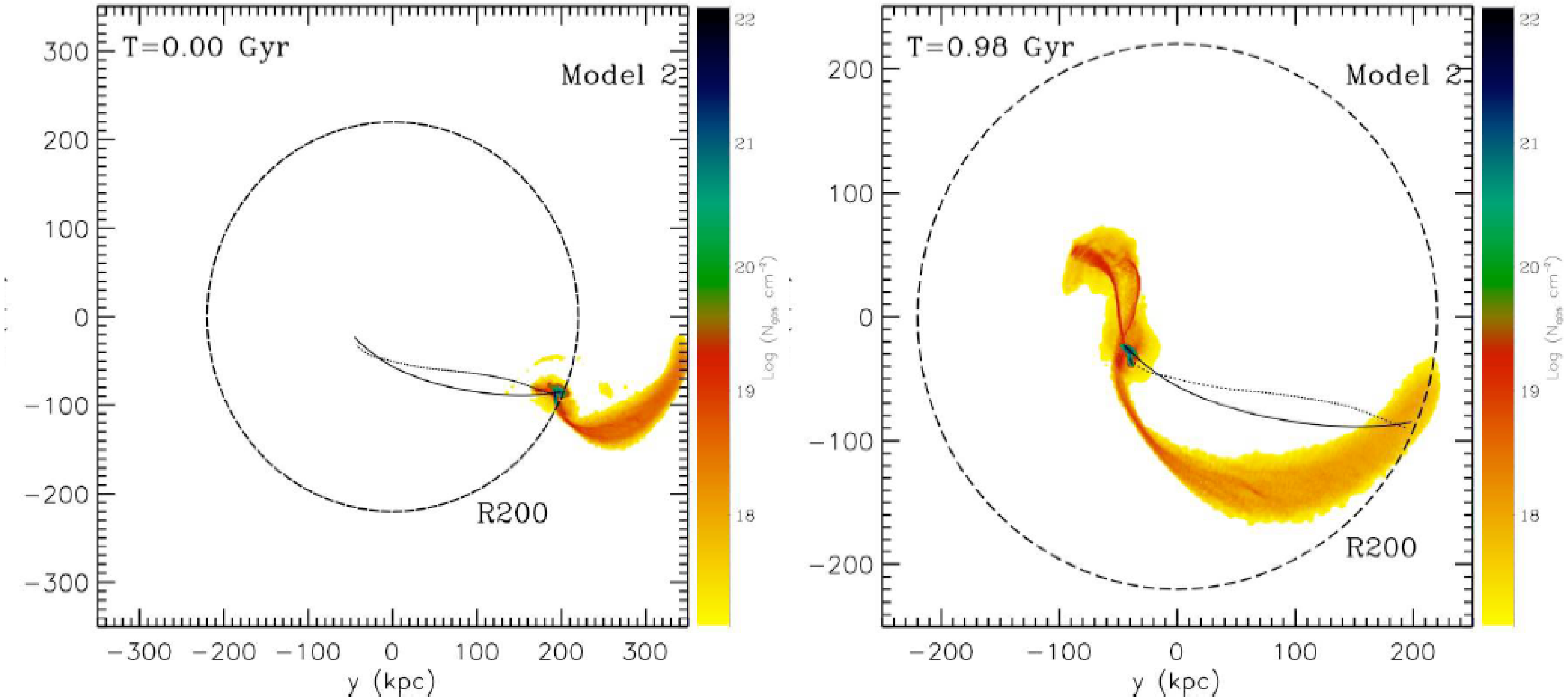
Constraint from the Magellanic Stream





- There is an obvious shift between the first passage model and the real MS.
- It indicates that we need the some new formation mechanism of the MS.

Constraint from the Magellanic Stream



Besla G. et al. 2012

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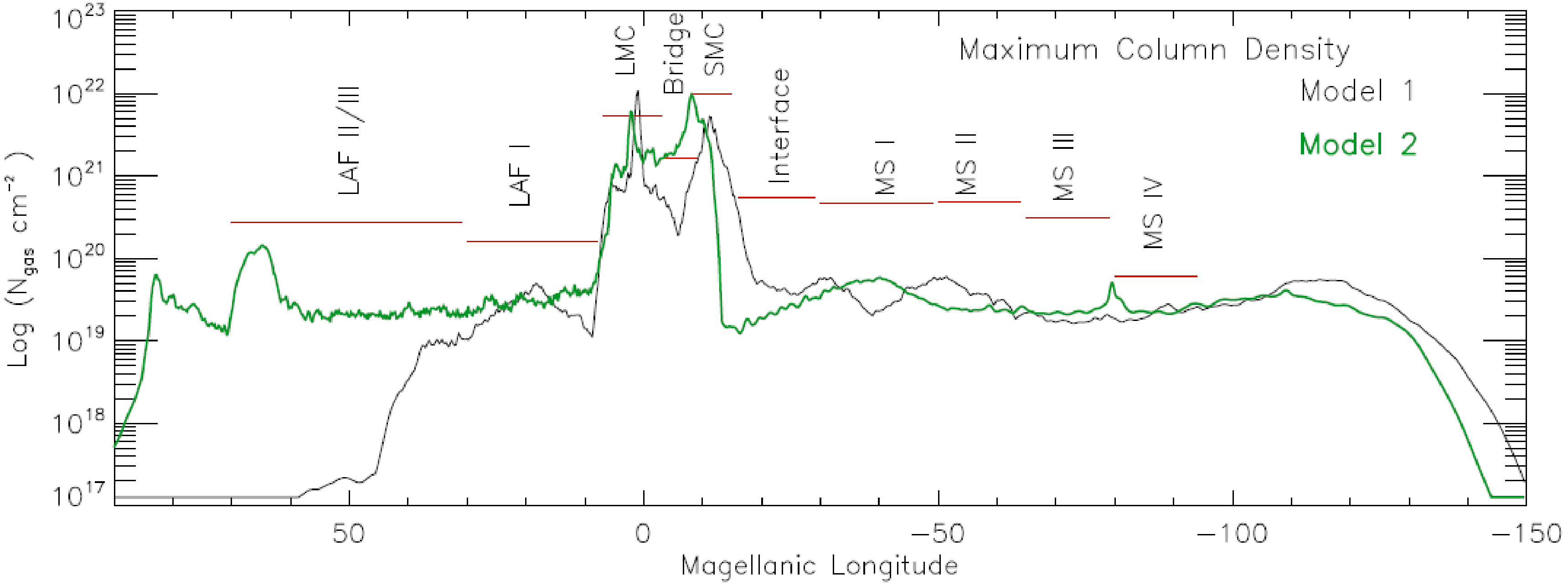
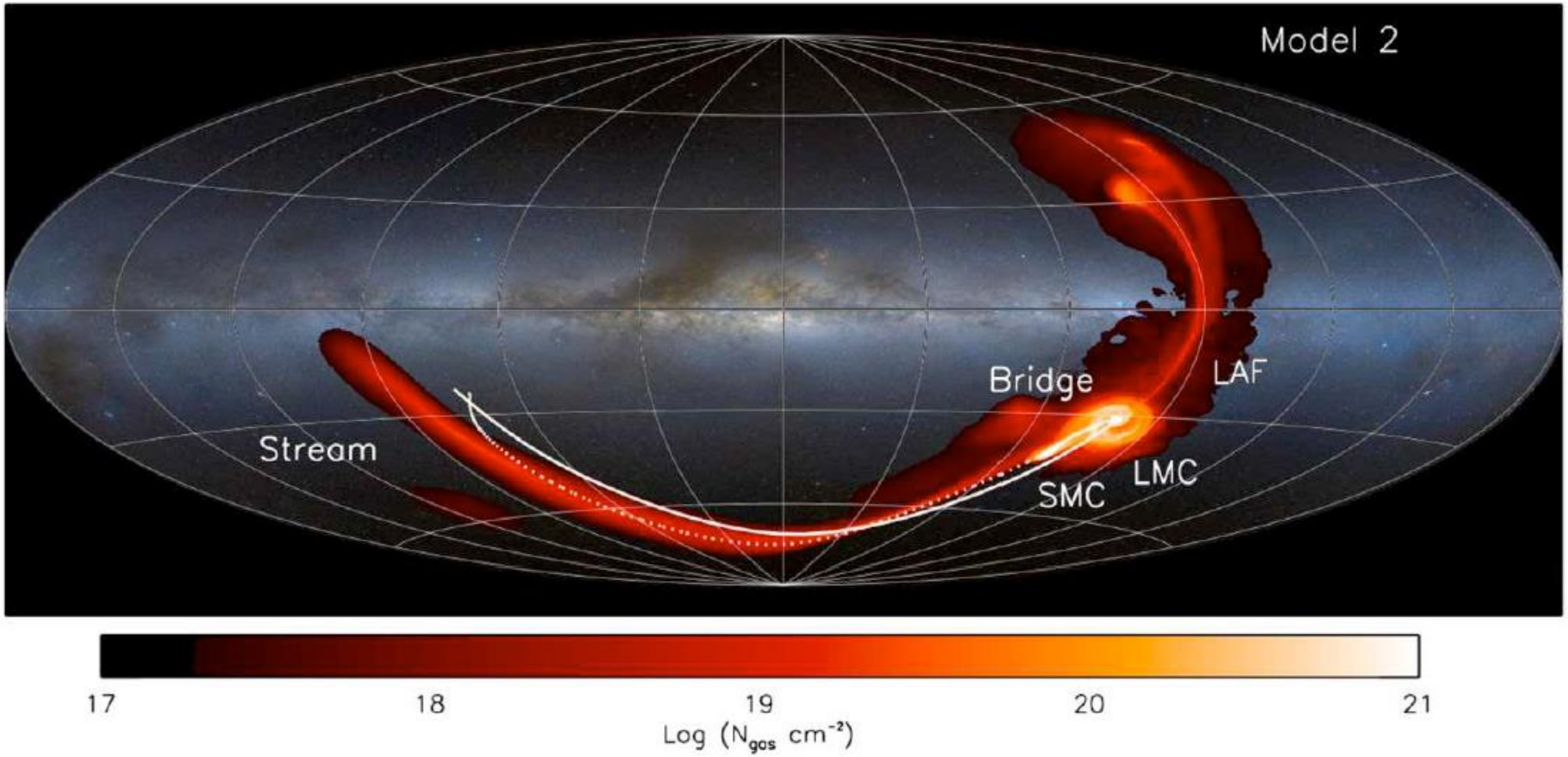


The model and observational gas density in the MS

Constraint from the Magellanic Stream



Why do we need the first passage model ?

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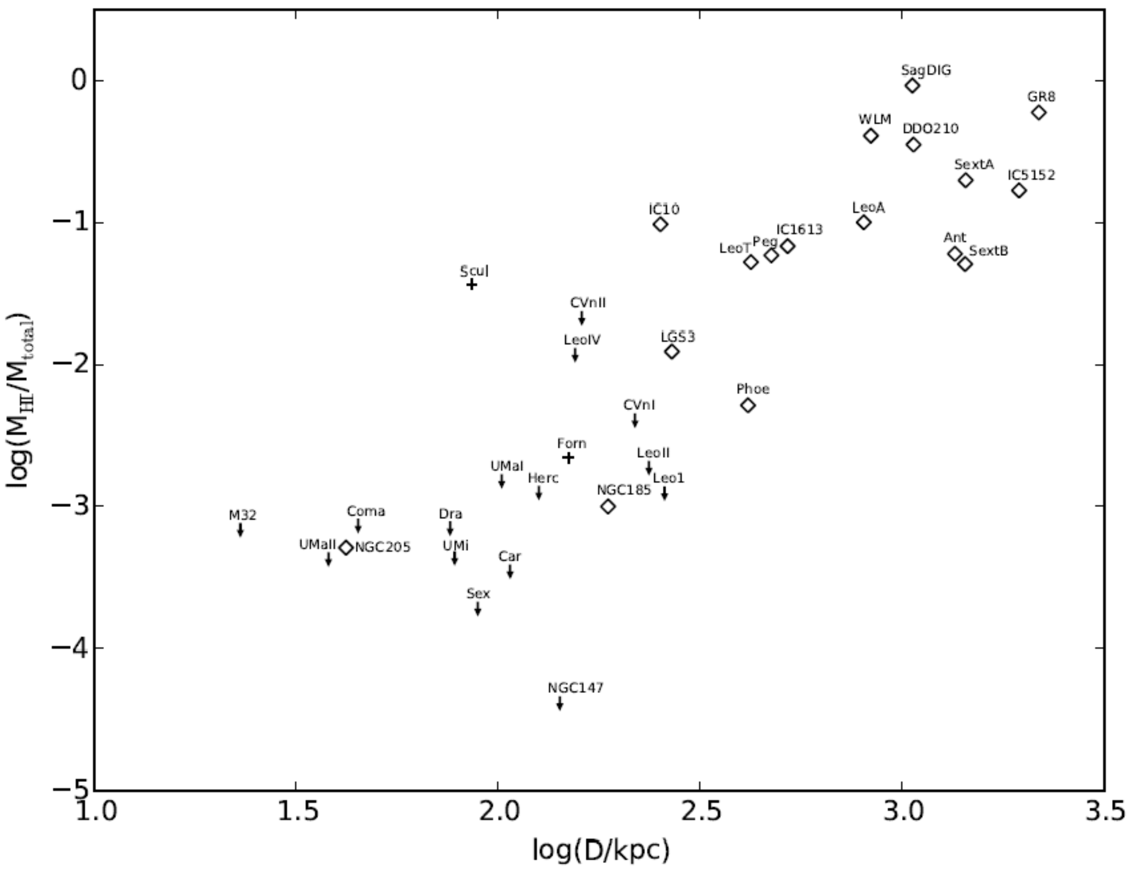
Correlation between the normalized HI mass and the galactocentric radius of the satellite of the MW & M31



Grcevich J. & Putman M. 2009

- The gas rich satellites are located at the larger galactocentric radius than the gas poor satellites

Why do we need the first passage model ?

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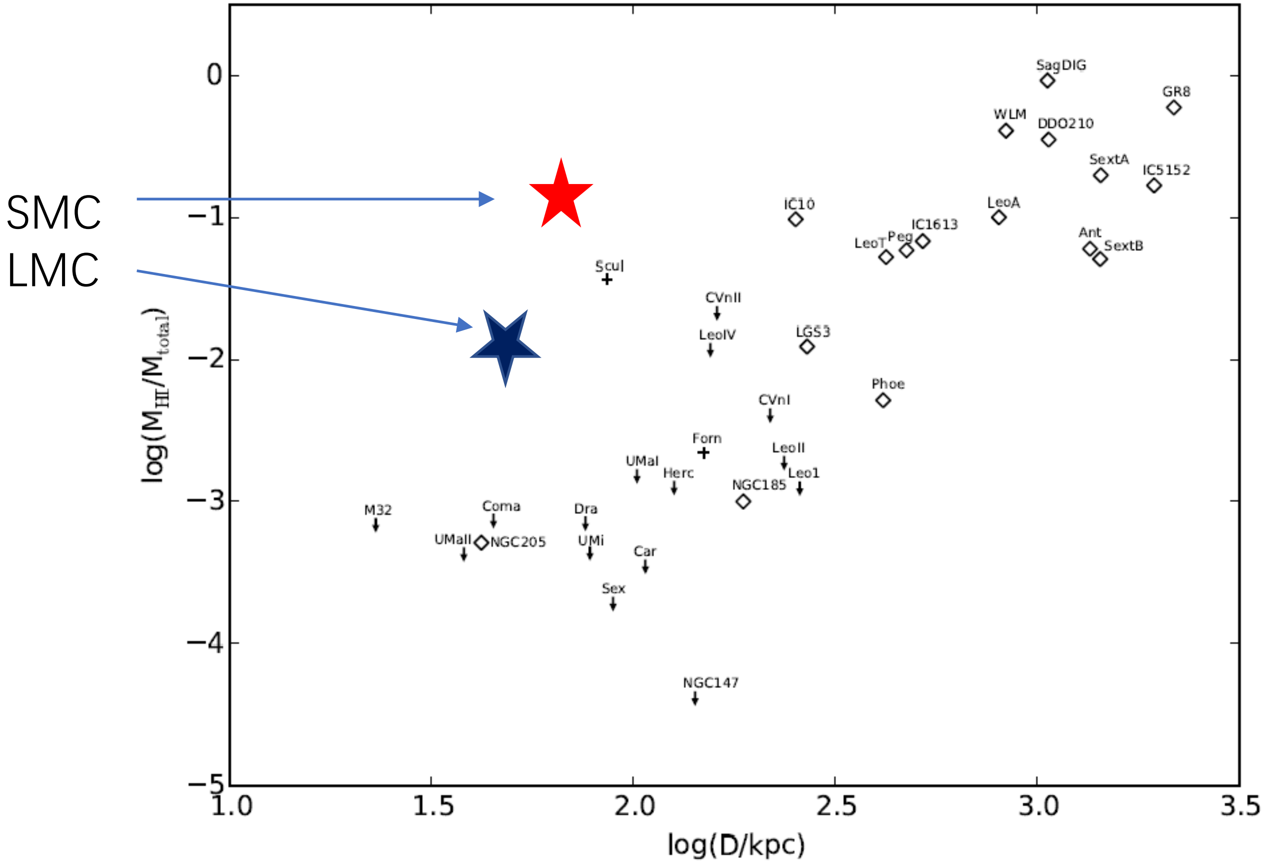
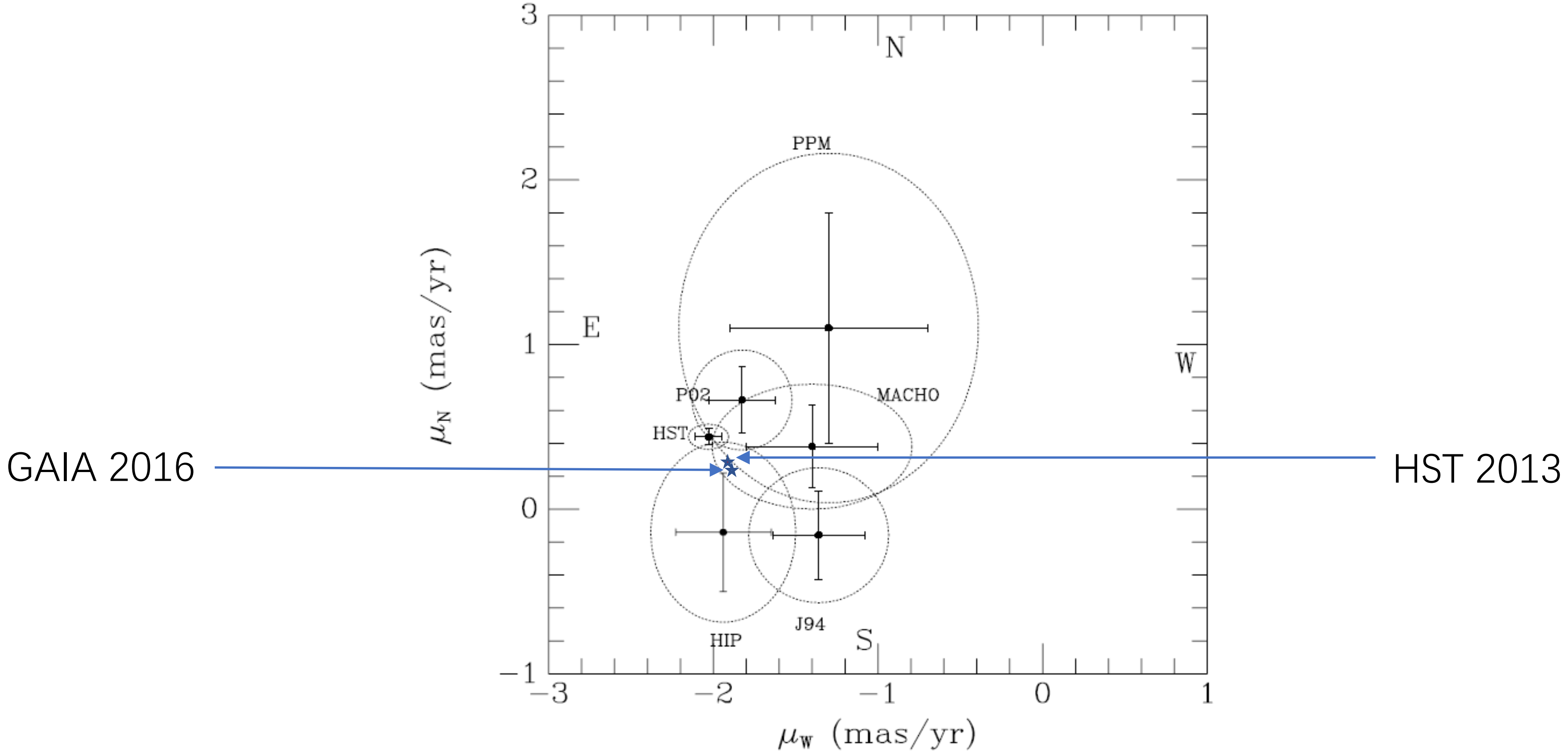


Grcevich J. & Putman M. 2009

- The gas rich satellites are located at the larger galactocentric radius than the gas poor satellites
- The MCs, at merely 50~60kpc, are notable exception to this relation.
- It indicates that the MCs experienced little gas distortion or accretion due to the interaction with the MW.

Recent proper motion measurements of MCs



Comments (Take Home Message)

- Both of the multiple and first passage scenario can fit the present position of the Magellanic Clouds in 6D phase space. But now the new proper motion measurements favor the first passage scenario.

- The first passage model could help explain the anomaly of the MCs in the galactocentric radius – HI mass relation of the local satellites.

- The model the MCs' orbit history need the more accurate measurements and mass model of the MW & MCs to provide the initial condition.

- The Magellanic stream formation mechanism can also affect the orbit history of the MCs.

Thanks for Listening