The Origin and Dynamics of the Local Group of Galaxies

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M31, M32, NGC205

Introduction

- Since the discovery of the Magellanic Stream, the dynamics of the Magellanic System is extensively studied. Tidal models of the Galaxy-LMC-SMC system success to reproducing the geometrical and dynamical structure of the MS (Murai and Fujimoto 1980, Gardiner, Sawa and Fujimoto 1994), and orbits of the LMC and SMC are well determined.
- However, some problems are remain.

LMC & SMC

Remaining Problems

- **The origins of the LMC and SMC**

  Did they initially form as satellite galaxies of the Galaxy, or did they fall into the Galaxy from another region.

- **Large orbital angular momenta of the Magellanic Clouds around the Galaxy**

  The tidal model in which the Magellanic Clouds formed in the neighborhood of the Galaxy cannot explain such large orbital angular momenta.

Some questions about must be answered through a more-global model for the LGG.

M33

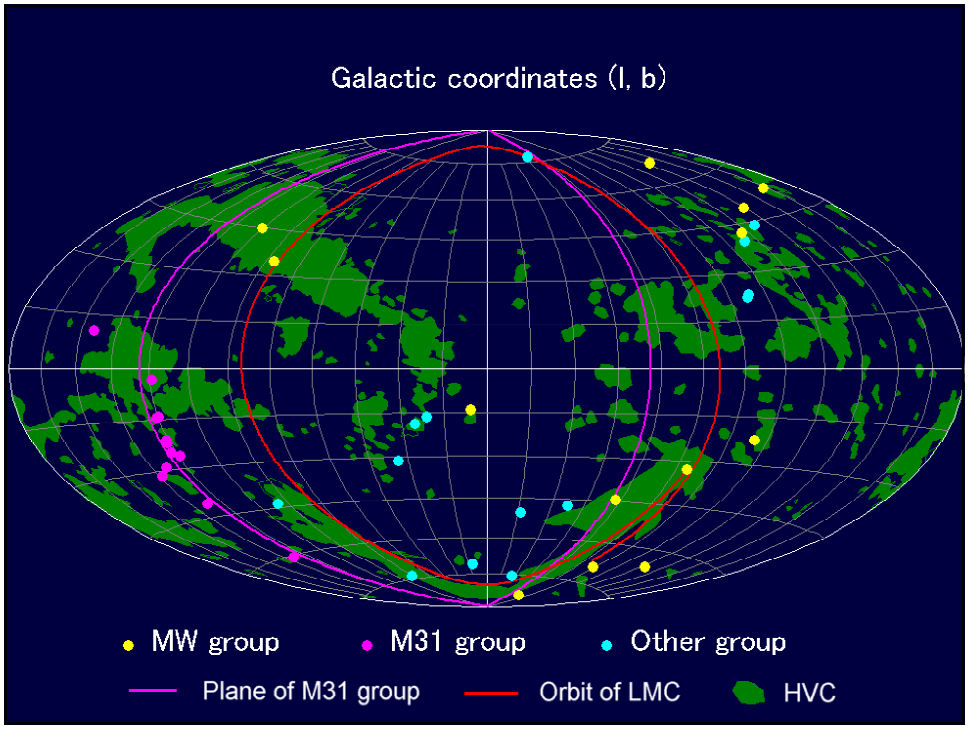
Sky Distribution of LGG

- **Many dwarf galaxies are distributed near the great circle perpendicular to the galactic plane.**
- **Magellanic Stream lies along this great circle.**
- **Members of M31 are distributed near this circle**

suggestion

A big dynamical event occurred in the neighborhood of the Galaxy about 10 Gyr ago

NGC3109



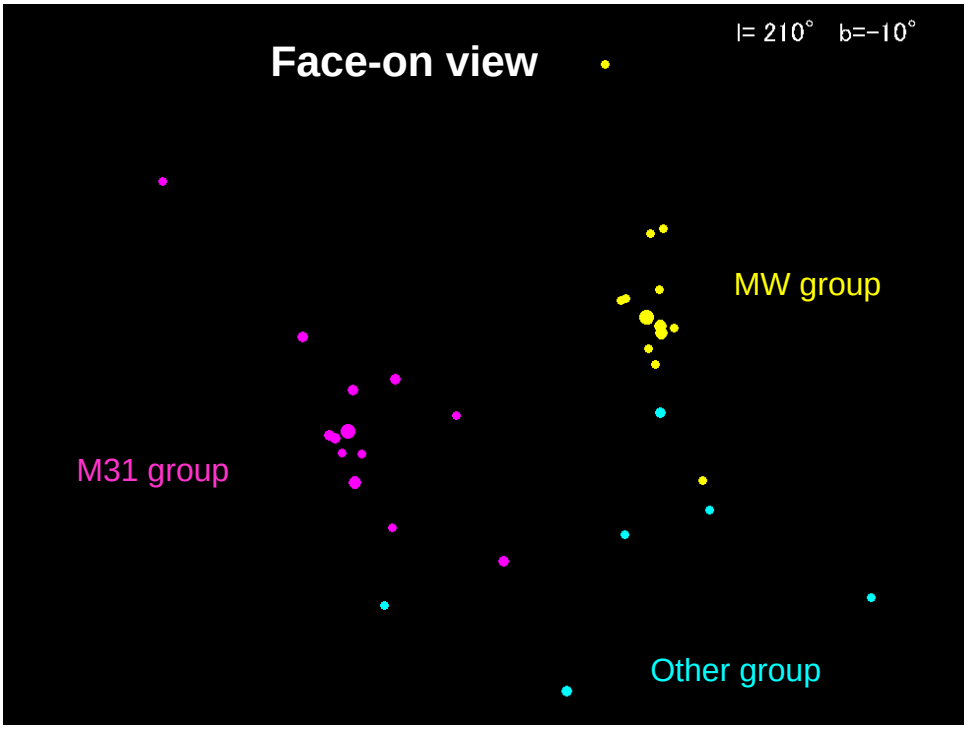
3-dimensional distribution of LGG

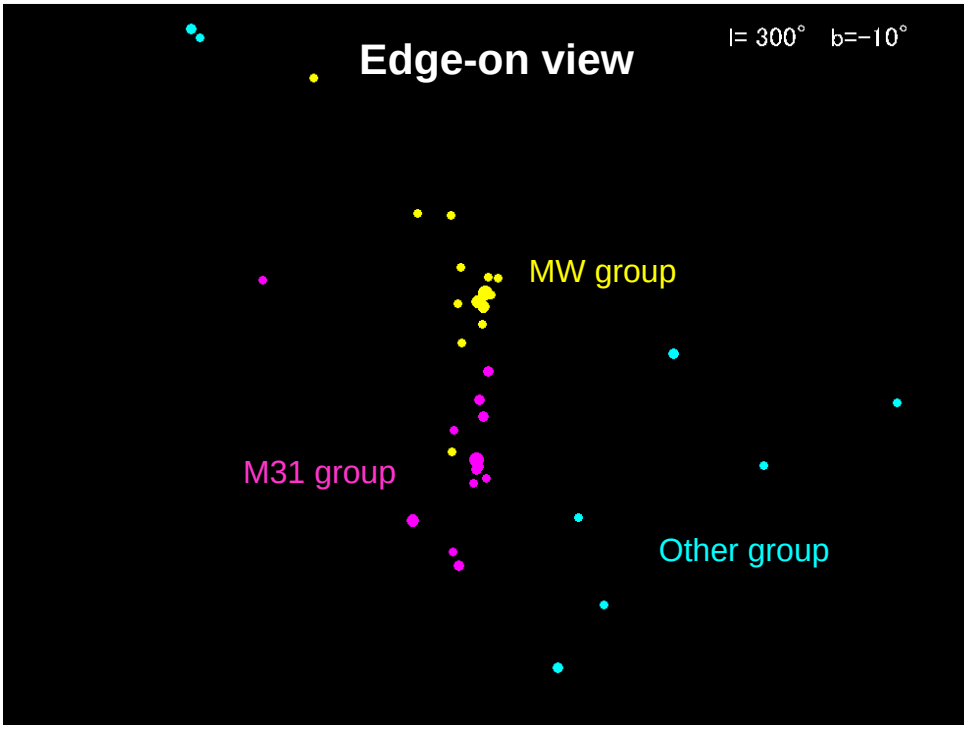
- **Many LGG members are distributed in a coplanar way**

New idea

An off-center hydrodynamical collision occurred some 10 Gyr ago between the primordial gas-rich M31 and the similar Galaxy, and compressed the halo gas to form the LGG dwarf galaxies.

NGC55


Face-on view
l= 210° b=−10°
MW group
M31 group
Other group


Edge-on view
l= 300° b=−10°
MW group
M31 group
Other group

Galaxy interaction and dwarf galaxies

- A many young dwarf galaxies are observed around the violently merging gas-rich galaxies（Deeg et al. 1998，A & Ap Suppl . 129，445）

It suggests the possibility that dwarf galaxies of Local Group are formed by the off-collision between the Galaxy and M31

Colliding Galaxies NGC 4038 and NGC 4039 HST • WFPC2
PRC97-34a • ST ScI OPO • October 21, 1997 • B, Whitmore (ST ScI) and NASA

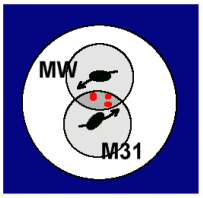
Our Model (SF Model)

Sawa and Fujimoto 2005, PASJ, 57

Many dwarf galaxies of LGG is formed by the off-center collision of proto-M31 and proto-Galaxy in early universe, and scattered in the present position.

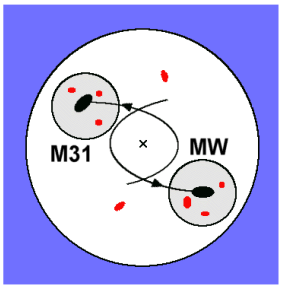
SMC

Scenario of our model



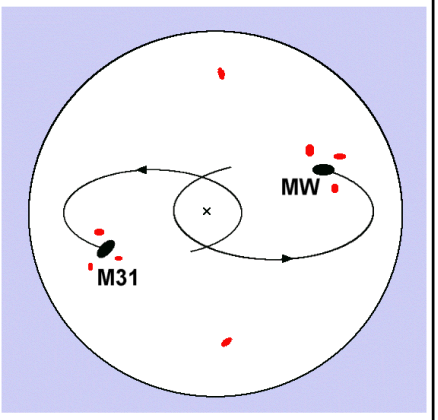
10 Gyr ago

Two massive proto-galaxies made a off-center collision.



5 Gyr ago

The newborn dwarf galaxies are scattered on the orbital plane of the Galaxy and M31.



Present time

M31 is again approaching us.

Assumption

- M31 and the Galaxy have massive halo
- The radius of massive halo is 200 - 300 kpc
- The radius of the proto galaxy is 120 kpc
- The collision is occurred about 10 Gyr ago
- LMC and SMC were formed by the collision

AAT 51

Leo I

Basic equation

$$M_A \ddot{r}_A = -\nabla_A \Phi_G - F_{GA}$$

$$M_G \ddot{r}_G = -\nabla_G \Phi_A - F_{AG}$$

$$M_L \ddot{r}_L = -\nabla_L (\Phi_A + \Phi_G + \Phi_S) - F_{AL} - F_{GL}$$

$$M_S \ddot{r}_S = -\nabla_S (\Phi_A + \Phi_G + \Phi_L) - F_{AS} - F_{GS}$$

$$M_D \ddot{r}_D = -\nabla_D (\Phi_A + \Phi_G + \Phi_L + \Phi_S)$$

M : mass of galaxy Φ : gravitation potential

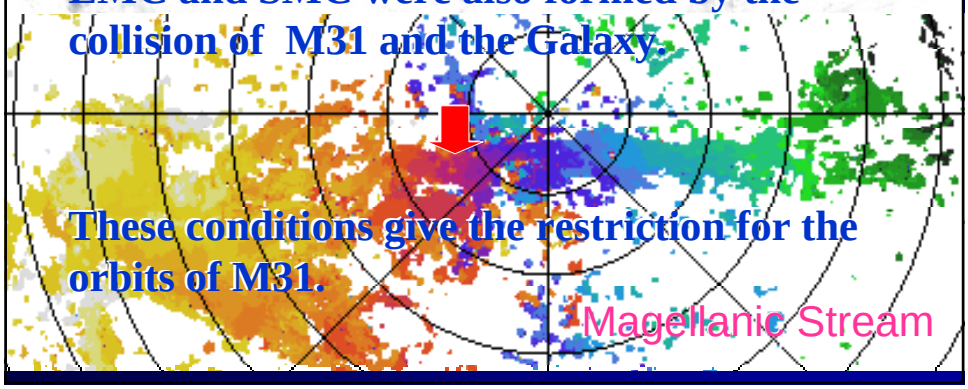
F : Dynamical Friction

NGC185 & 147

The orbit of M31

The orbits of LMC and SMC are well determined by the presence of Magellanic Stream.

LMC and SMC were also formed by the collision of M31 and the Galaxy.



These conditions give the restriction for the orbits of M31.

Magellanic Stream

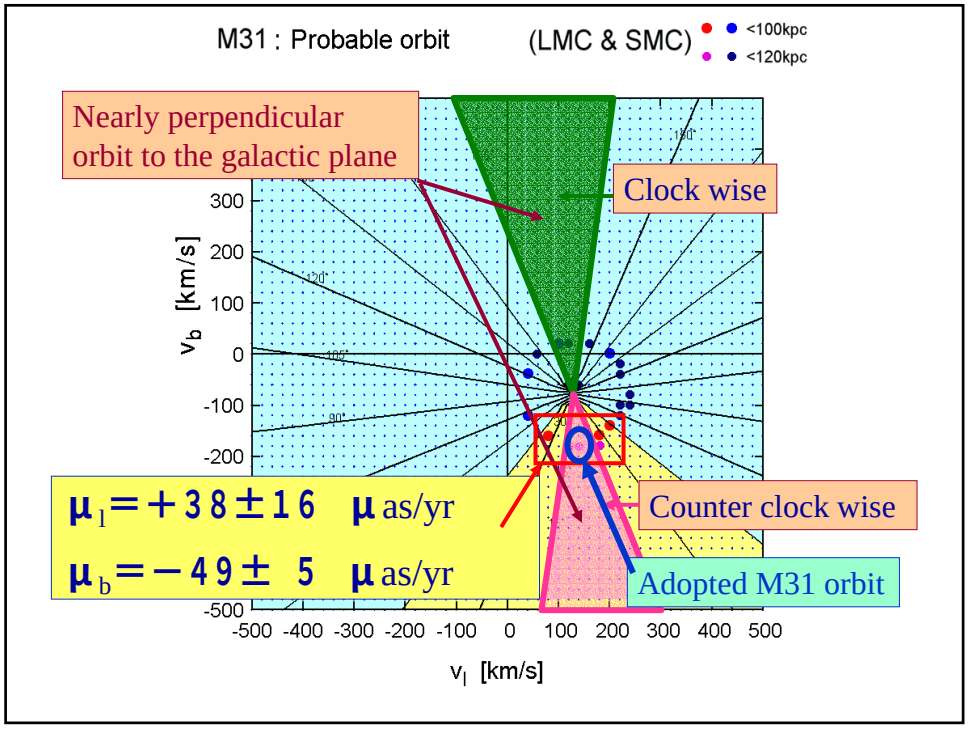
Determination of the M31 orbit

The orbits of LMC and SMC of that by Gardiner, Sawa & Fujimoto (1994) are used

Four bodies problem of M31-Galaxy-LMC-SMC are solved.

We search the M31 orbits such as the LMC and SMC are formed by the collision of M31 and the Galaxy.

LMC



Relation between the collision time and radius of massive halo

Number of possible orbits of M31

radius ＼ time	9-10 Gyr	10 -11 Gyr	11-12 Gyr
200 kpc	–	–	1
230 kpc	–	1	–
250 kpc	4	2	–
280 kpc	4	3	–
300 kpc	–	5	–

ΔV_l=20 km/s , ΔV_b=20 km/s

NGC6822

Orbits of the Galaxy group

- Angle between the orbital planes of M31 and dwarf galaxy is less than 30 °
- Dwarf galaxy orbits the Galaxy counter-clockwise seen from the present position of the sun
- Dwarf galaxy located the formation site about 10-12 Gyr ago

Sextans A

Orbit of M31 group

- Angle between the orbital planes of M31 and dwarf galaxy is less than 30°
- Orbital angular momentum of dwarf galaxy has the same direction as that of M31
- Dwarf galaxy located the formation site about 10-12 Gyr ago

IC10

A Sheet of score for model orbits

WLM	×	Sculptor	○	Sextans B	×	Sagittarius	○
NGC55	×	LGS3	○	NGC3109	×	SagDIG	×
IC10	○	IC1613	○	Antlia	×	NGC6822	×
NGC147	○	And II	–	Leo I	○	DDO 210	×
And III	–	M33	○	Sextans A	×	IC5152	×
NGC185	○	Phoenix	○	Sextans	○	Tucana	–
NGC205	○	Fornax	○	Leo II	○	UKS2323-326	×
M32	○	EGB0427+63	×	GR8	×	Pegasus	○
M31	○	LMC	○	Ursa Minor	○		
And I	–	Carina	○	Draco	○		
SMC	○	Leo A	×	Milky Way	○		

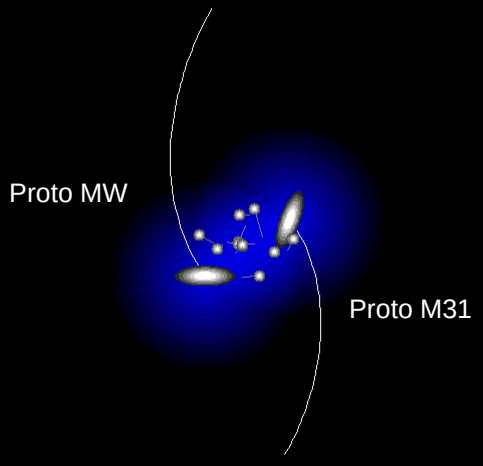
Possible orbits：23/37 (62%) Our Galaxy

Simulation for dwarf galaxy formation

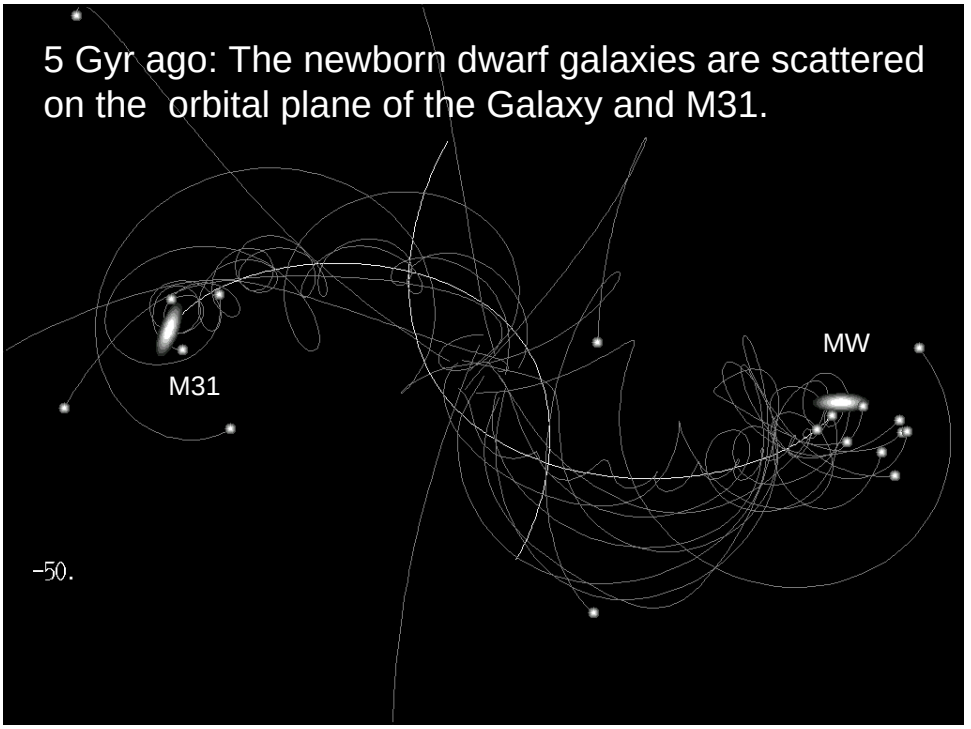
3-dimensional distribution of orbits

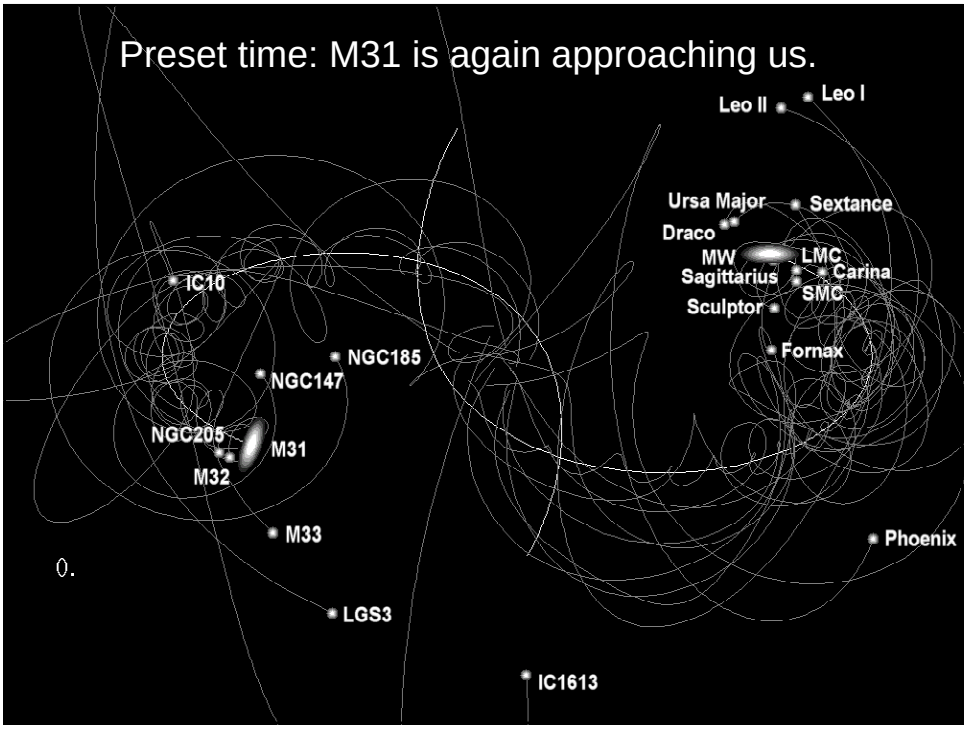
Pegasus

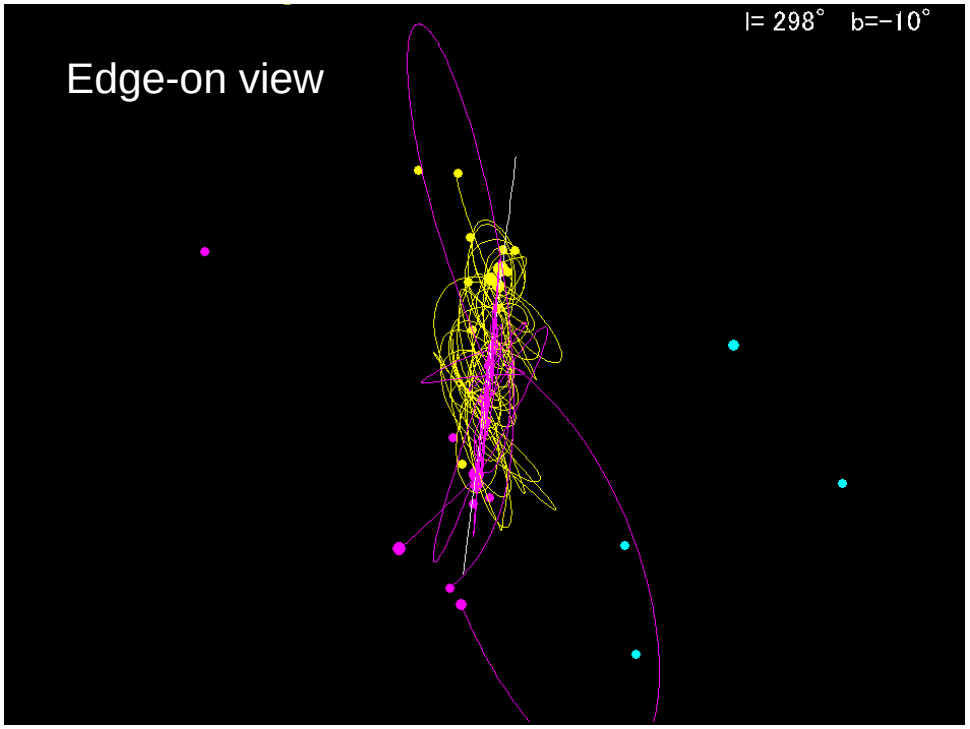
10 Gyr Ago: Two massive proto-galaxies made a off-center collision.

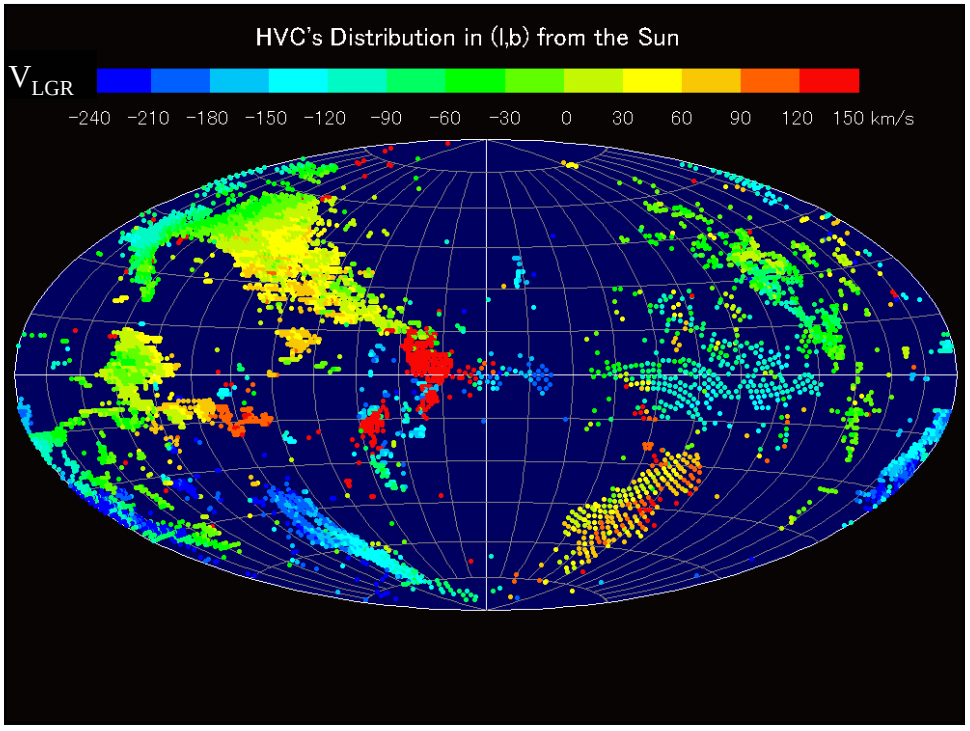


103.


5 Gyr ago: The newborn dwarf galaxies are scattered on the orbital plane of the Galaxy and M31.
M31
MW
-50.


Preset time: M31 is again approaching us.
Leo II
Leo I
Ursa Major
Sextance
Draco
MW
LMC
Carina
Sagittarius
SMC
Sculptor
Fornax
IC10
NGC185
NGC147
NGC205
M31
M32
M33
Phoenix
0.
LGS3
IC1613

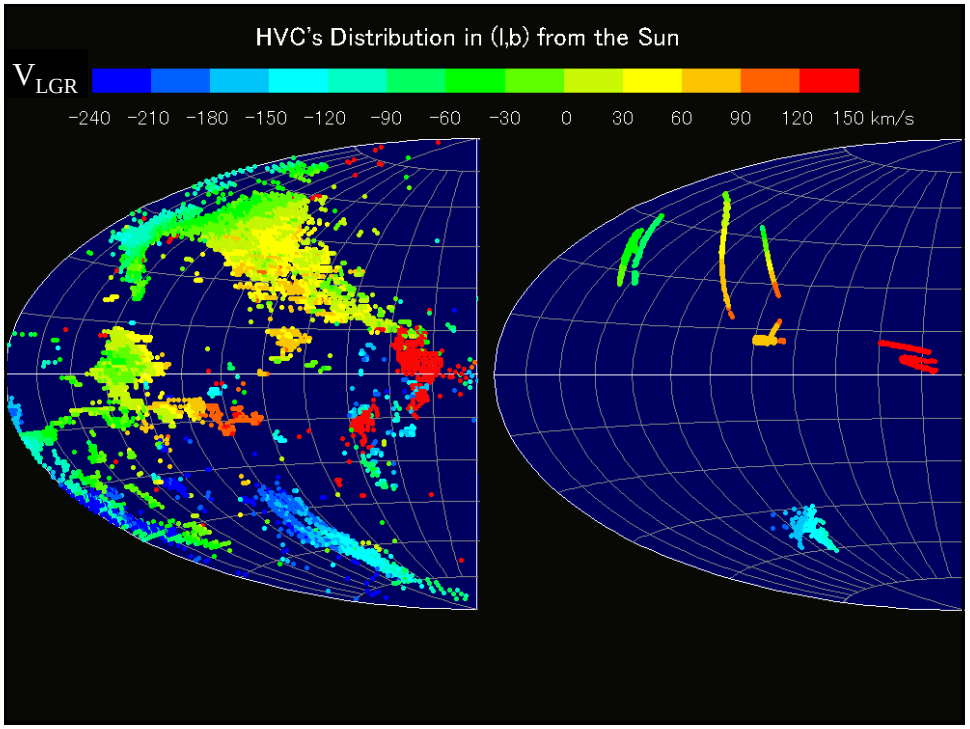

l= 298° b=−10°
Edge-on view


HVC's Distribution in (l,b) from the Sun
V_LGR
−240 −210 −180 −150 −120 −90 −60 −30 0 30 60 90 120 150 km/s

A Model of the origin of HVCs

- **Some HVCs are formed by collision of M31 and the Galaxy, too.**
- **We search the HVC orbits which satisfy the present position and radial velocity.**

WLM



Summary

- LGG members of the Galaxy group and M31 group distribute in a coplanar way
- It is possible to explain that these dwarf galaxies and some HVC were formed by the off-center collision between the Galaxy and M31 (SF model)
- The Galaxy and M31 need to have dark halo of 200 - 300 kpc radius, respectively
- We predict the proper motion of M31 as follows;

$\mu_l = +38 \pm 16$ μas/yr

$\mu_b = -49 \pm 5$ μas/yr

Phoenix