Major merger origin for M31 and its impact in the whole Local Group

(Has Milky way received something from Andromeda galaxy ?)

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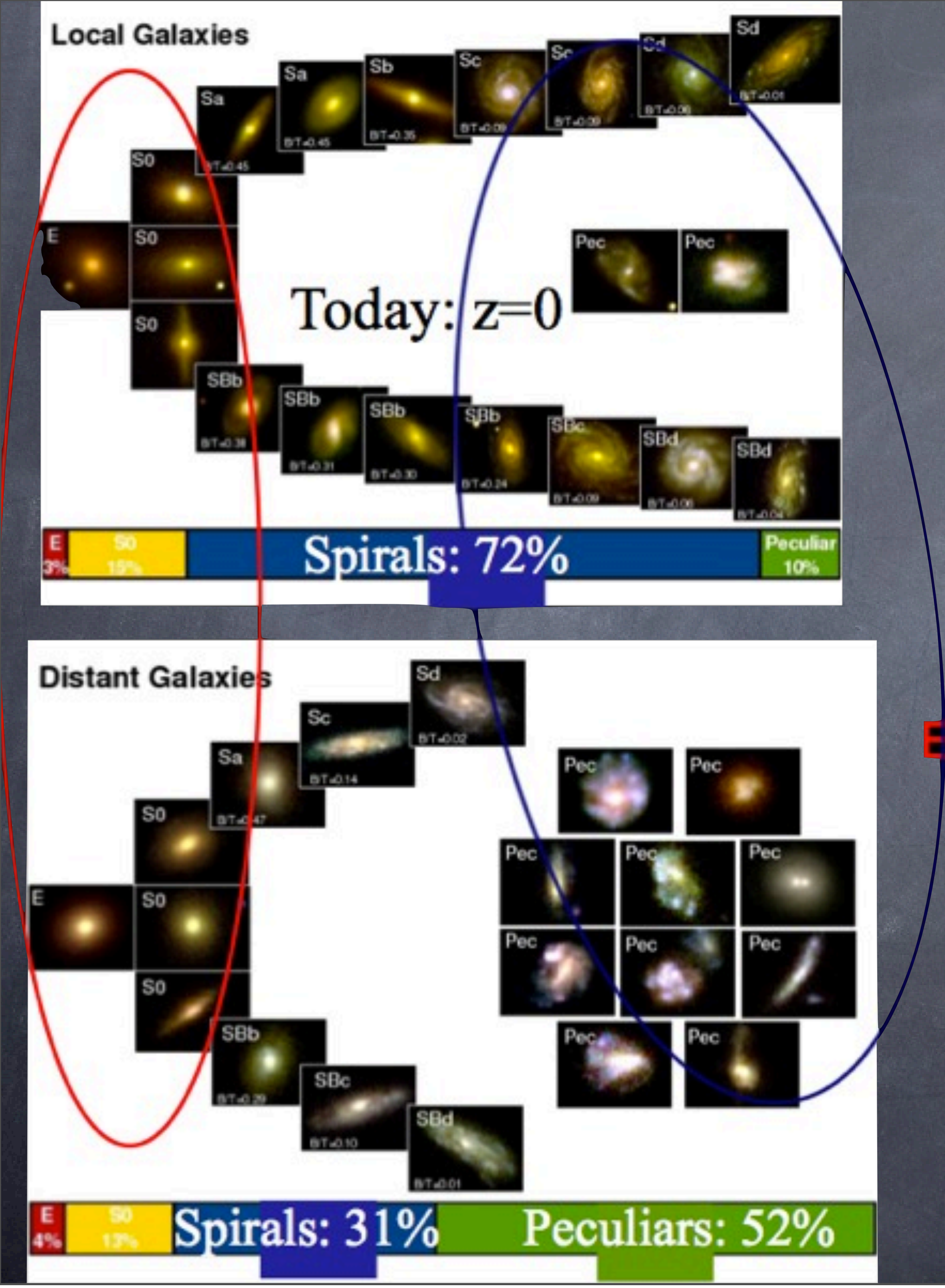
(ref:Hammer et al. 2010 and Yang&Hammer 2010)

2011.03.21@GEPI



$M_{J(AB)} < -20.3$

$\sim M_{stellar} > 1.5\ 10^{10} M_{\odot}$

Delgado et al. 2010

arXiv0906.2805

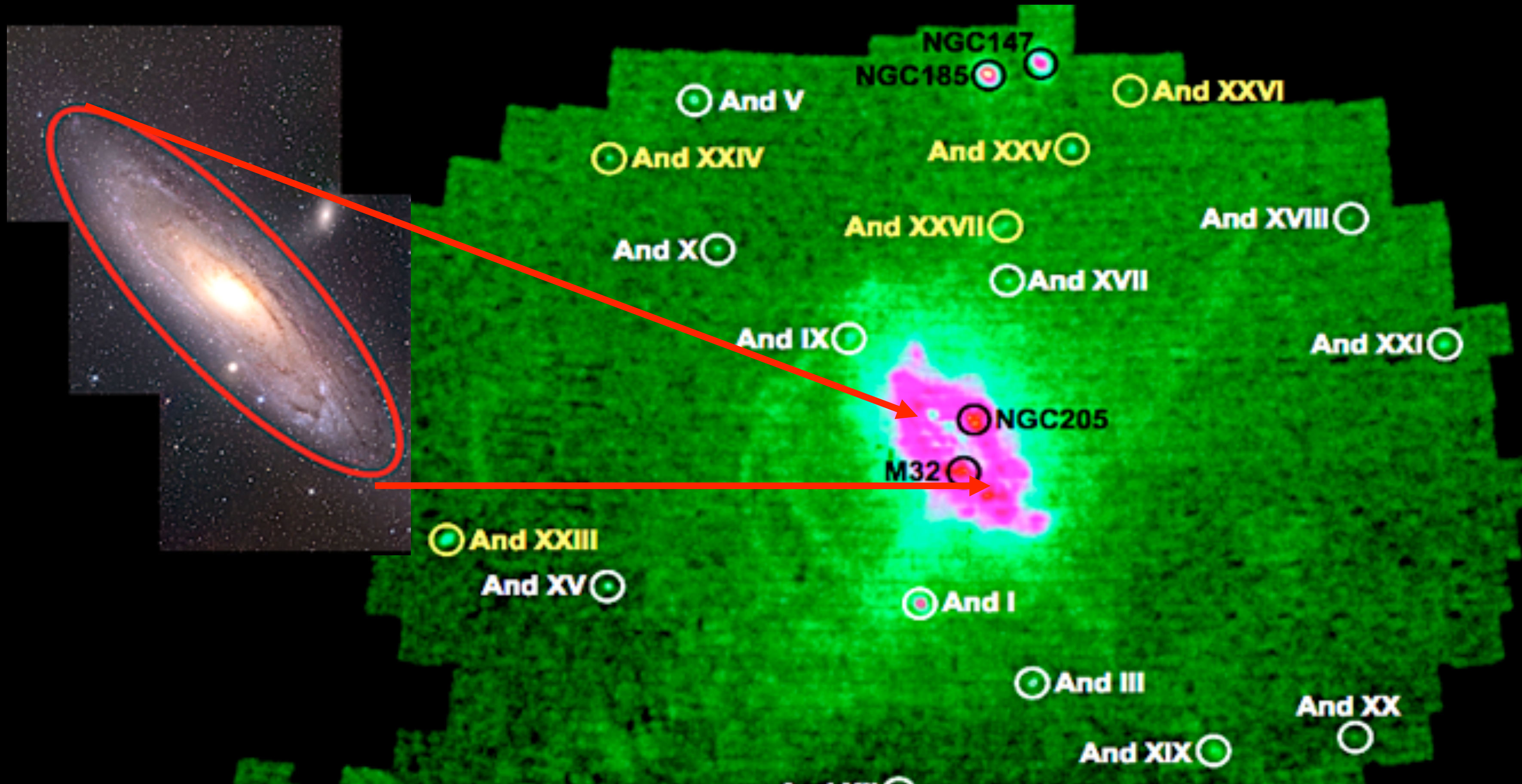
6 Gyrs ago, z=0.65:

E/S0 were mostly in place

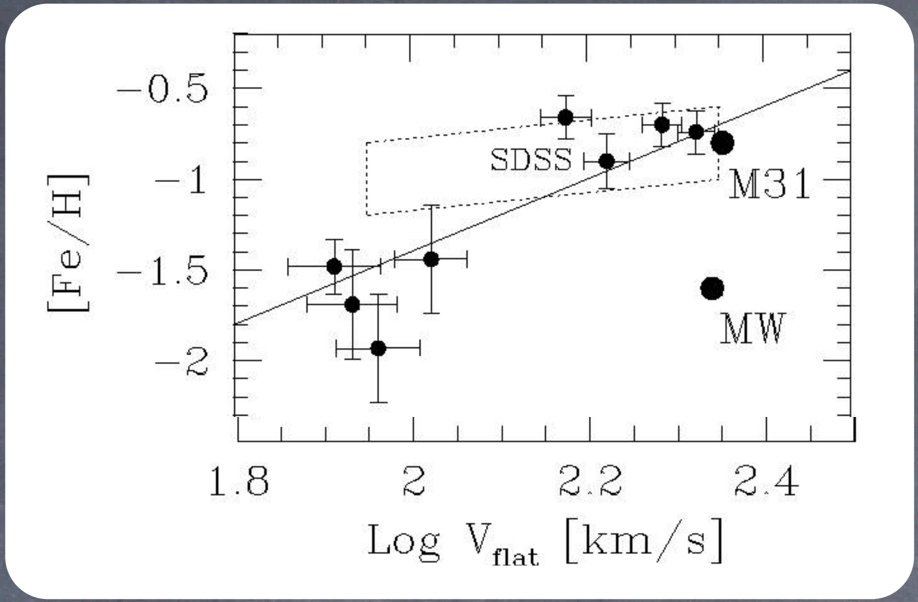
Half of spirals did not

➔ they had peculiar morphologies and anomalous kinematics

cf. Hammer et al. 2009

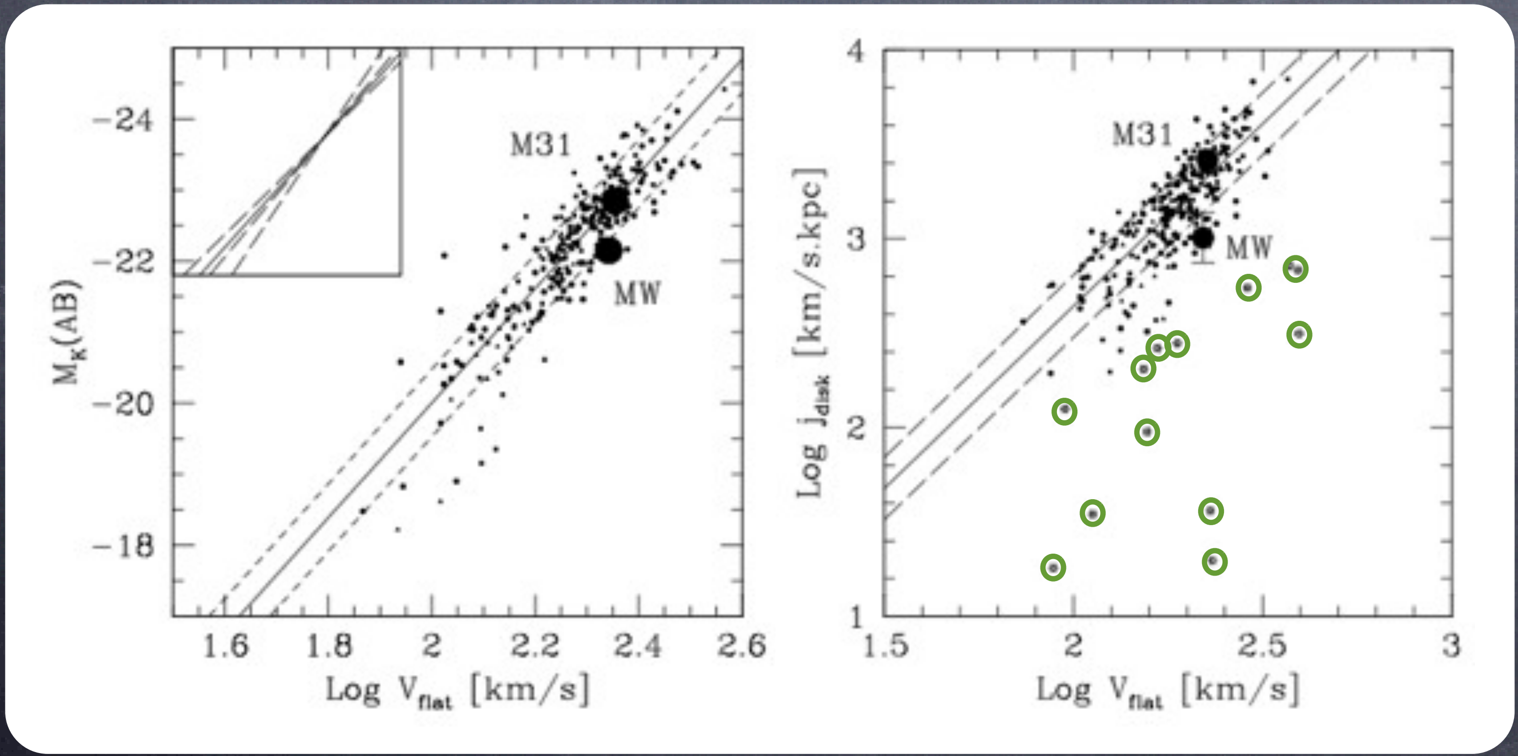


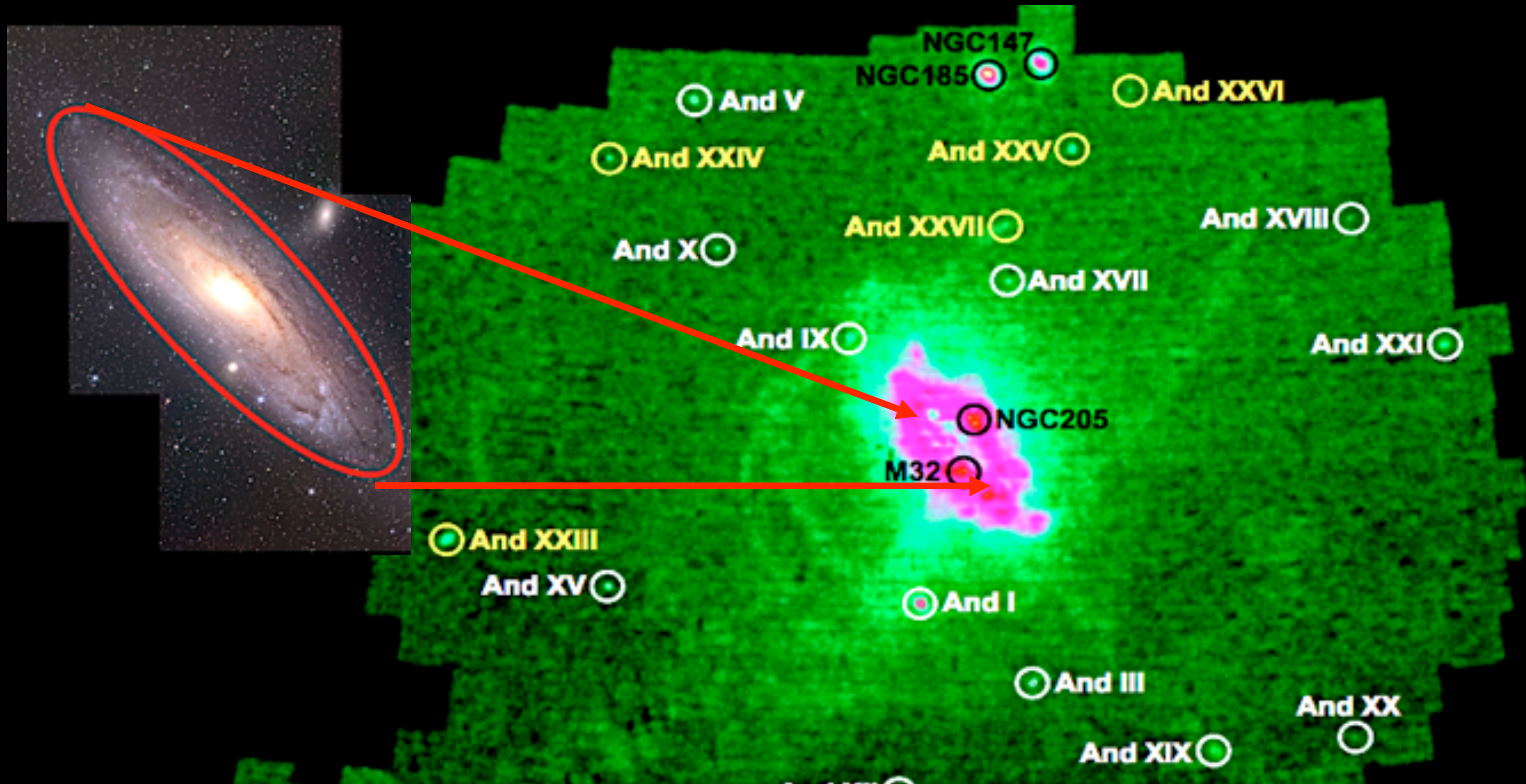
- a typical Spiral galaxy (Hammer et al. 2007)
- Classical bulge (Kormendy & Kennicutt 2004)
- More than 15-20 stellar streams, including Giant Stream (Ibata et al. 2001, 2005;McConnachie, Richardson et al. 2011;)
- All are linked to independent accretion events of subhalos (minor mergers). (Tanaka et al 2010) really ??
- Why similar metallicity in halo stellar population ? (Ferguson et al. 2005)
- Major merger? (Rich 2004, Ibata et al. 2004, Brown et al, 2006, Bekki 2010, van den Bergh 2005)



Hammer et al. 2007

Steinmetz&Navarro.1999





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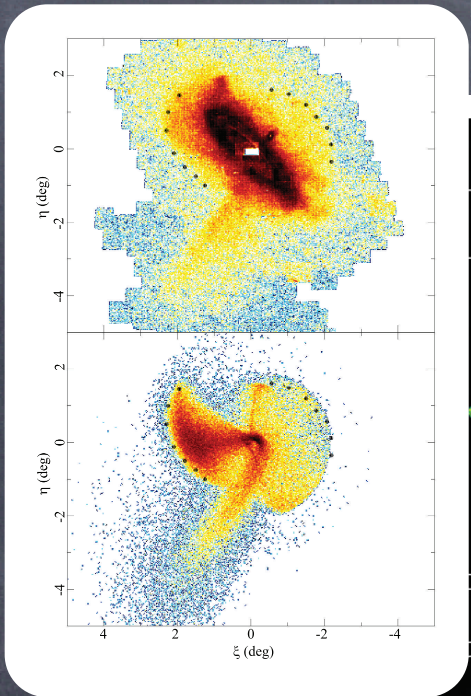
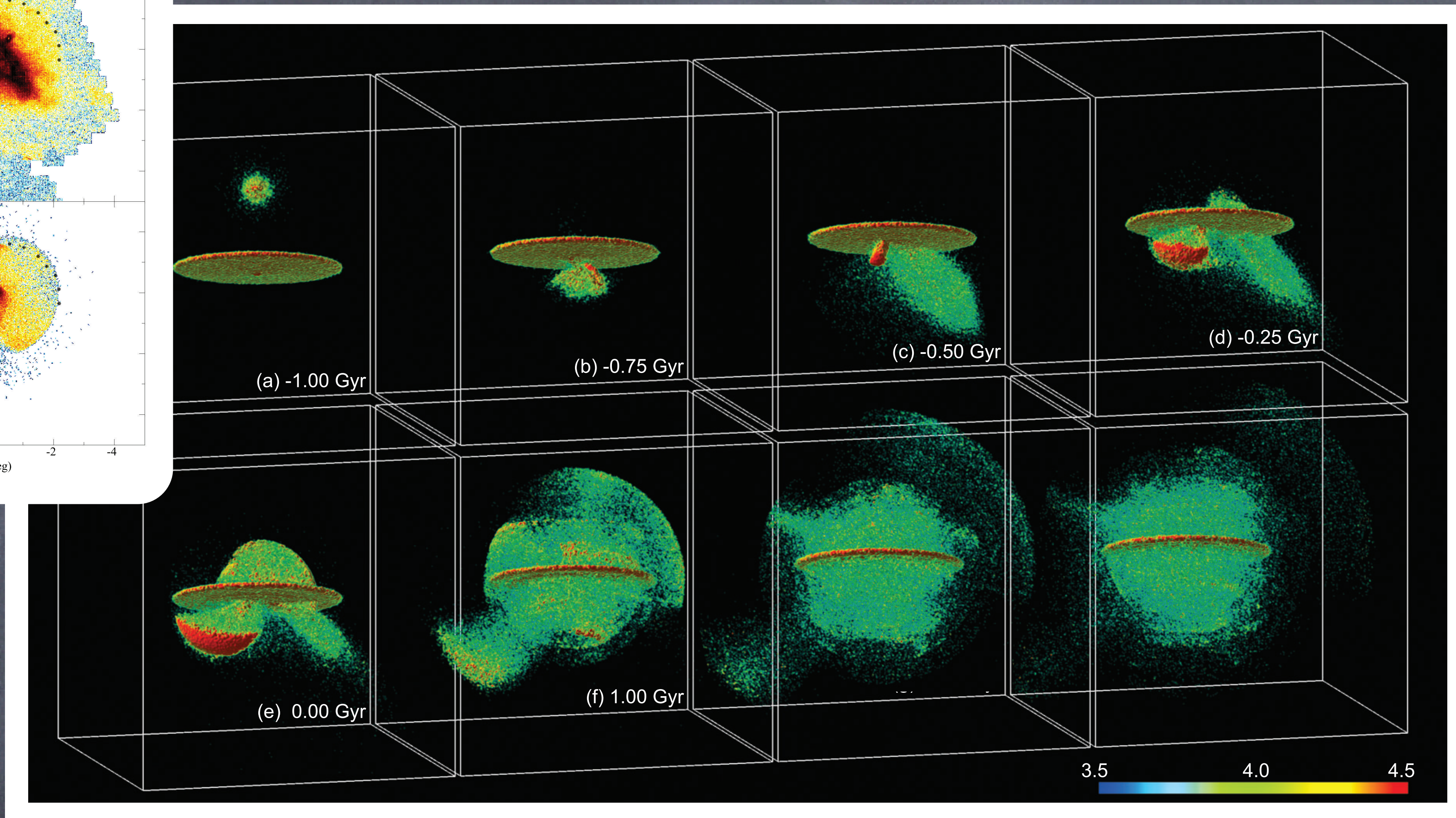
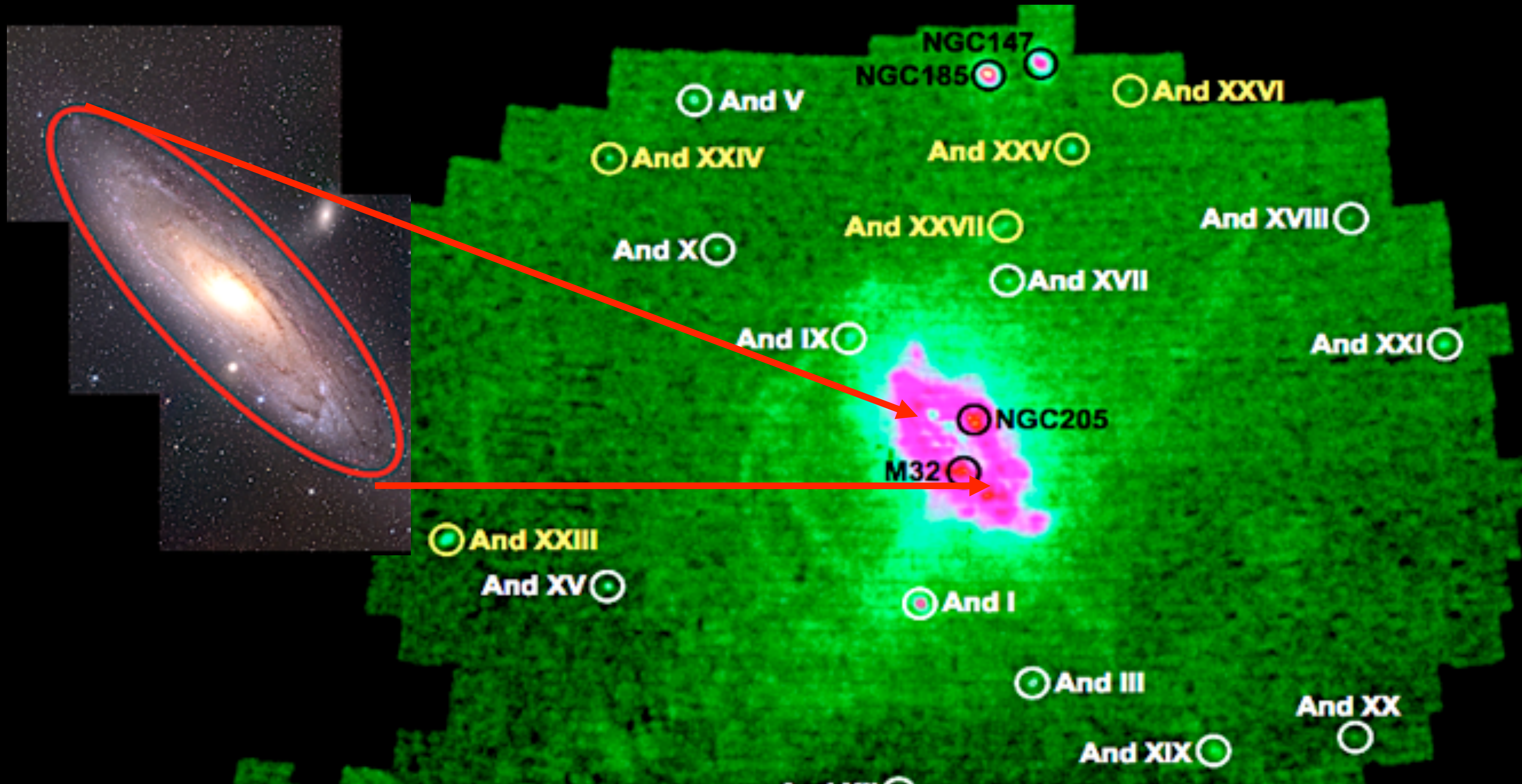




Mori & Rich 2008

Font et al. 2008: the presence of intermediate-age stars and the absence of young stars suggest that the satellite could have been accreted as long ago as 6-7 Gyr. If the satellite was accreted more than 1-2 Gyr ago, a continuation of the stream should exist in the halo of M31, about < 2 mag arcsec^2 fainter than the currently observed one.



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When?

1st passage

2nd passage

fusion

8Gyr

5Gyr

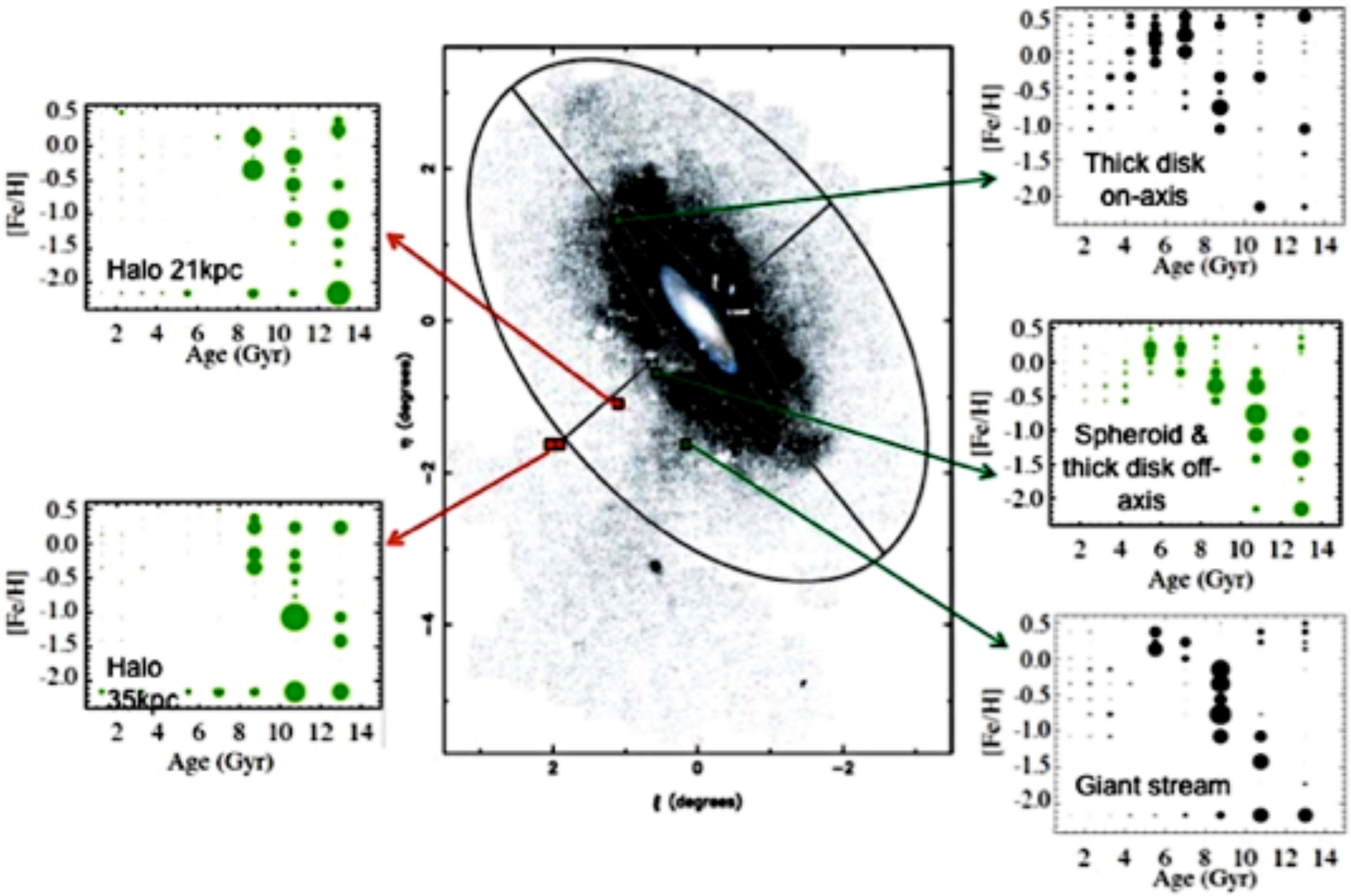
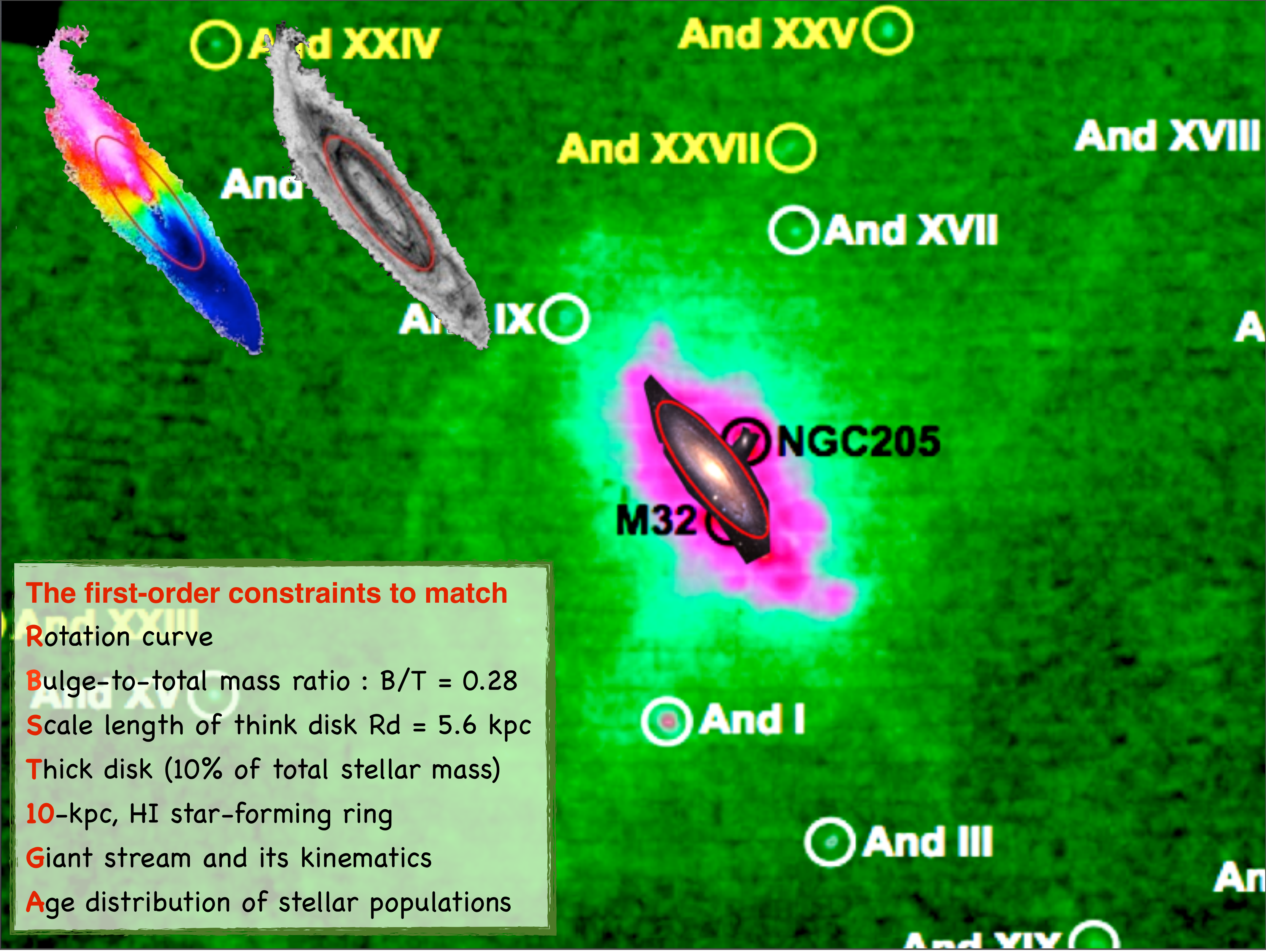


Fig. 1.— Chronological sketch of the structures surrounding M31. In the central panel (reproduced from Ibata et al. 2005), the large and thick rotating disk is a vast flattened structure with a major axis of about 4 degrees. Squares represent fields observed by Brown et al. (2006, 2007, 2008), and are linked to their measurements by arrows.

How?
First-order Constraints



The first-order constraints to match

Rotation curve

Bulge-to-total mass ratio : B/T = 0.28

Scale length of think disk Rd = 5.6 kpc

Thick disk (10% of total stellar mass)

10-kpc, HI star-forming ring

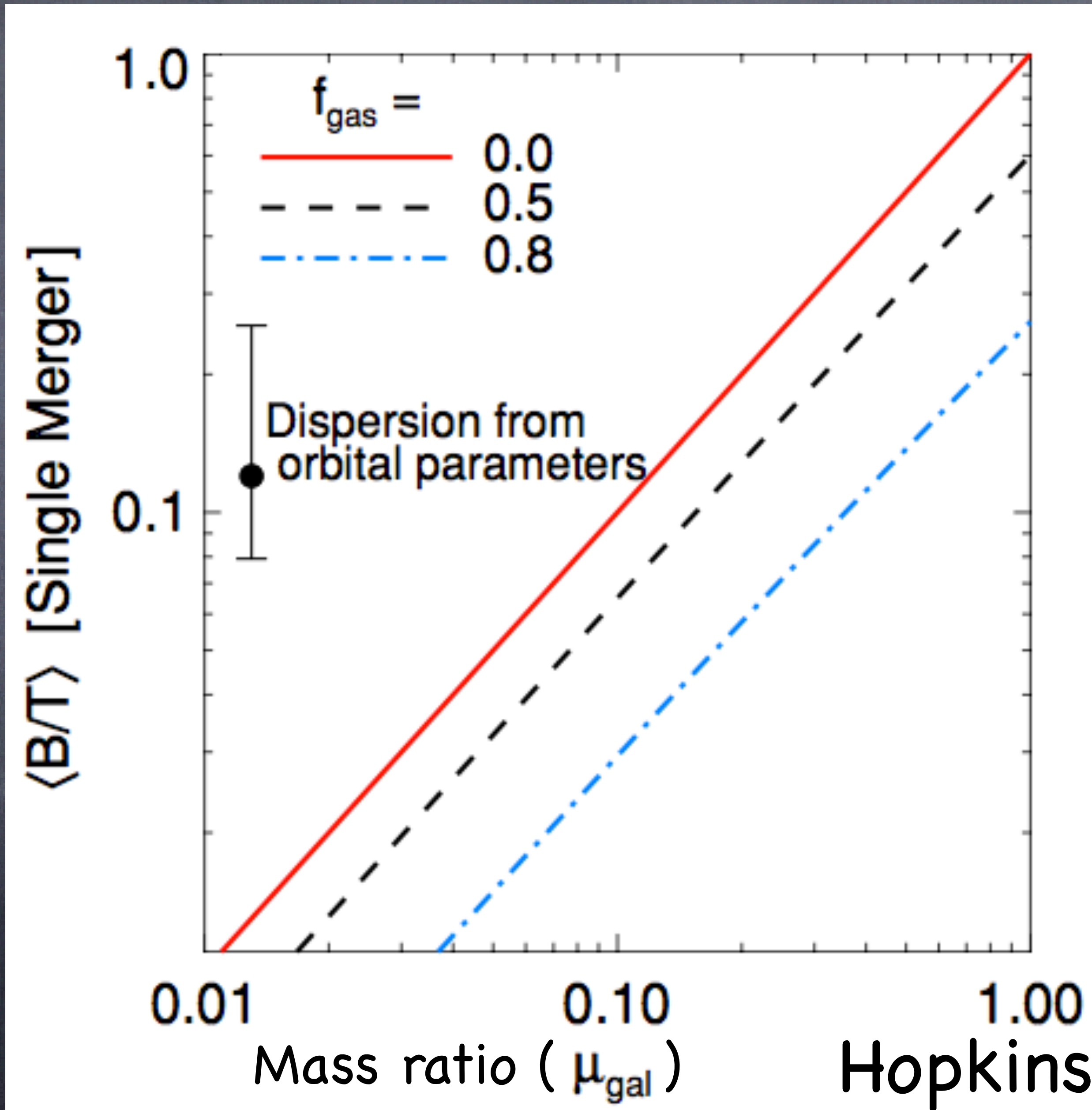
Giant stream and its kinematics

Age distribution of stellar populations

First-order Constraints ==> model setup

constraint	initial model info.
age distribution	pericentric distance; high fraction at redshift; galaxy size
10 kpc HI ring	polar type orbit
B/T = 0.28	mass ration/gas fraction (Hopkins, 2010)
GS + oirentation	spin of the minor galaxy main galaxy Inc.

B/T - mass ratio - gas fraction



Hopkins et al. 2010

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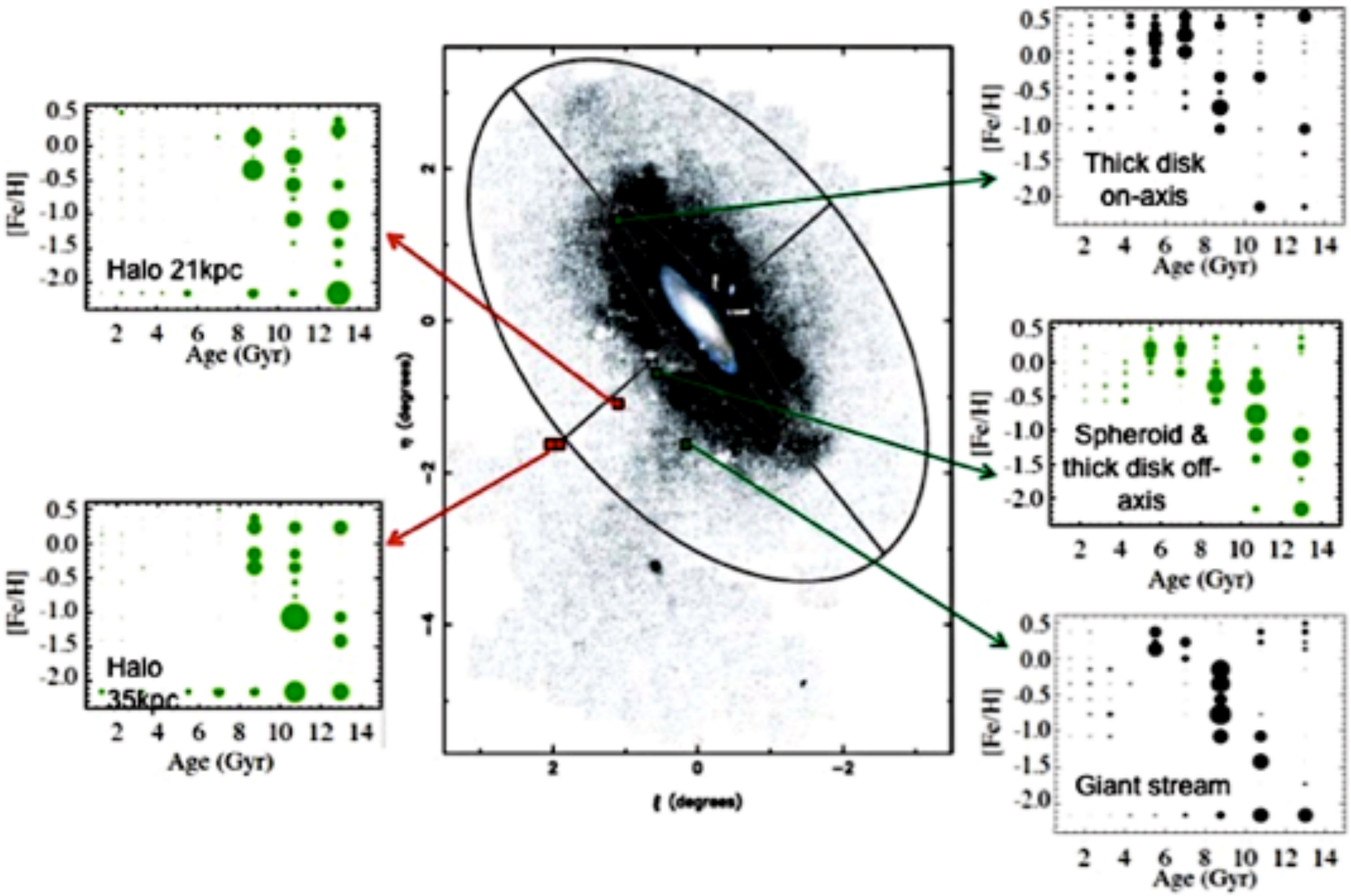
1st passage 2nd passage 3rd? or fusion



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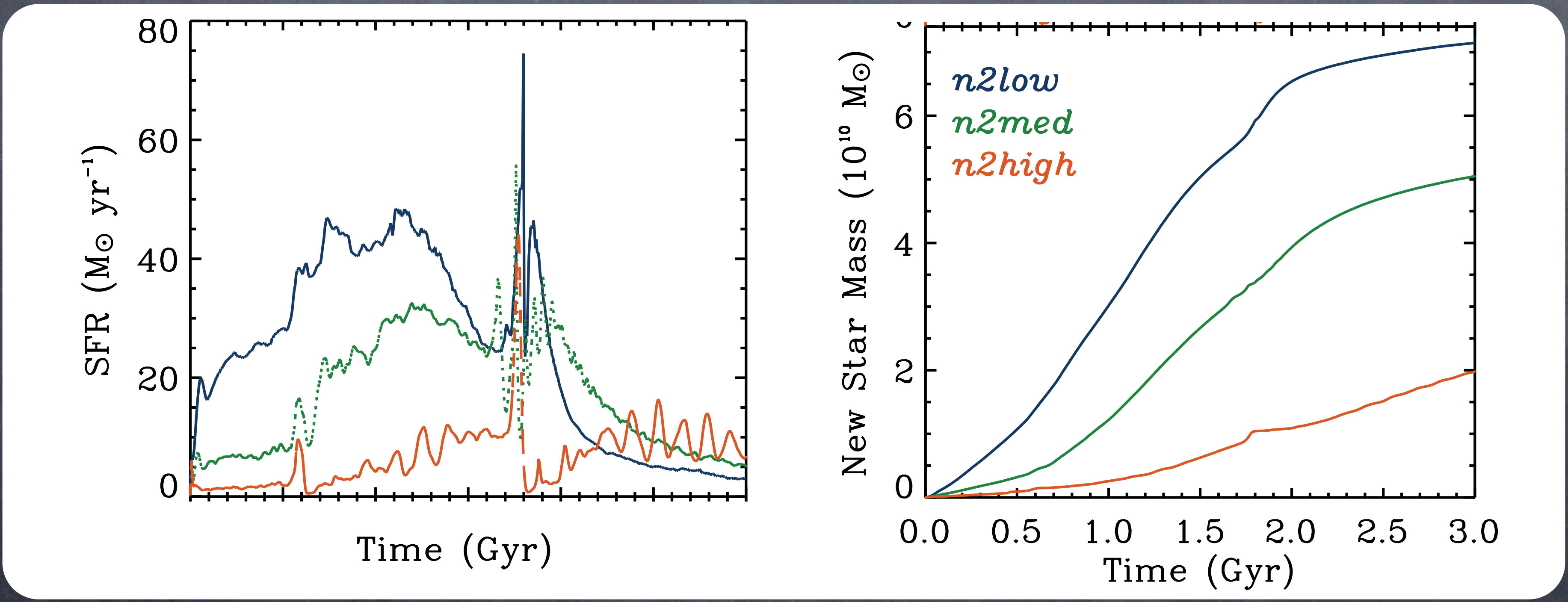
N-body/SPH model of major merger with Gadget2

- Gaget2, public version. 2.0.6 (Springel 2005)
- developed an efficient interactive tool to exam the simulation result.
- Gas cooling, Feedback & Star formation (Cox, 2006; Wang et al. In preparation)
- We adopt a star formation history that is

Star formation prescription

- Feedback & Star formation (Cox, 2006)



Constant feedback!

Star formation prescription

- Feedback & Star formation close to realistic

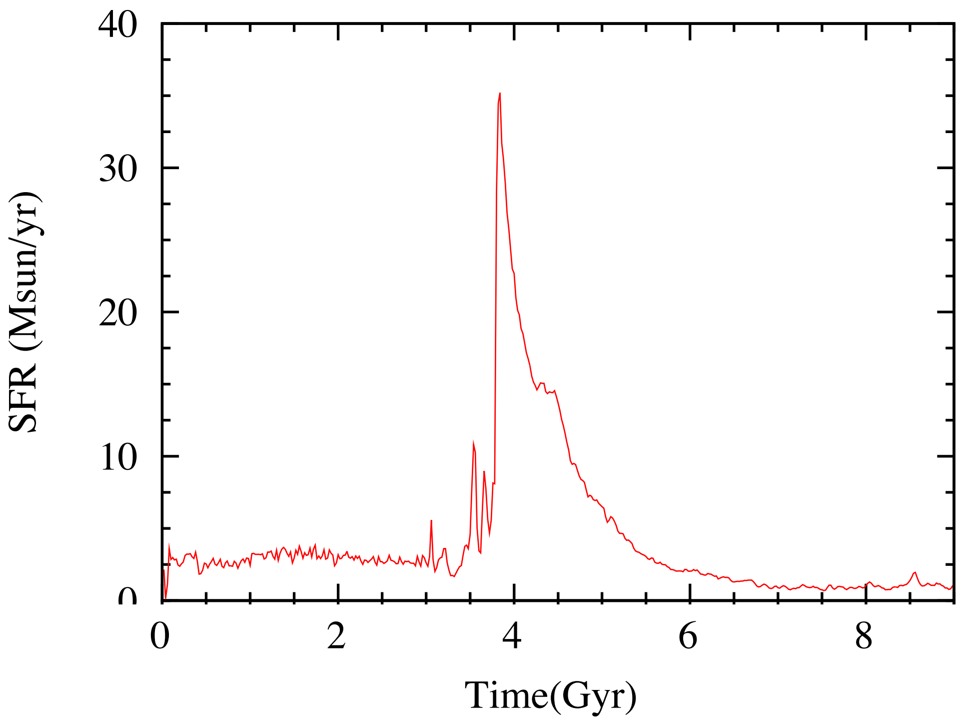
	progenitor (z>1-1.5)	re-formed disk
metallicity	low	moderate/high
feedback	high	low
cooling	inefficient	efficient
gas density (Kennicutt-Schmidt law)	low (may below)	high (above)

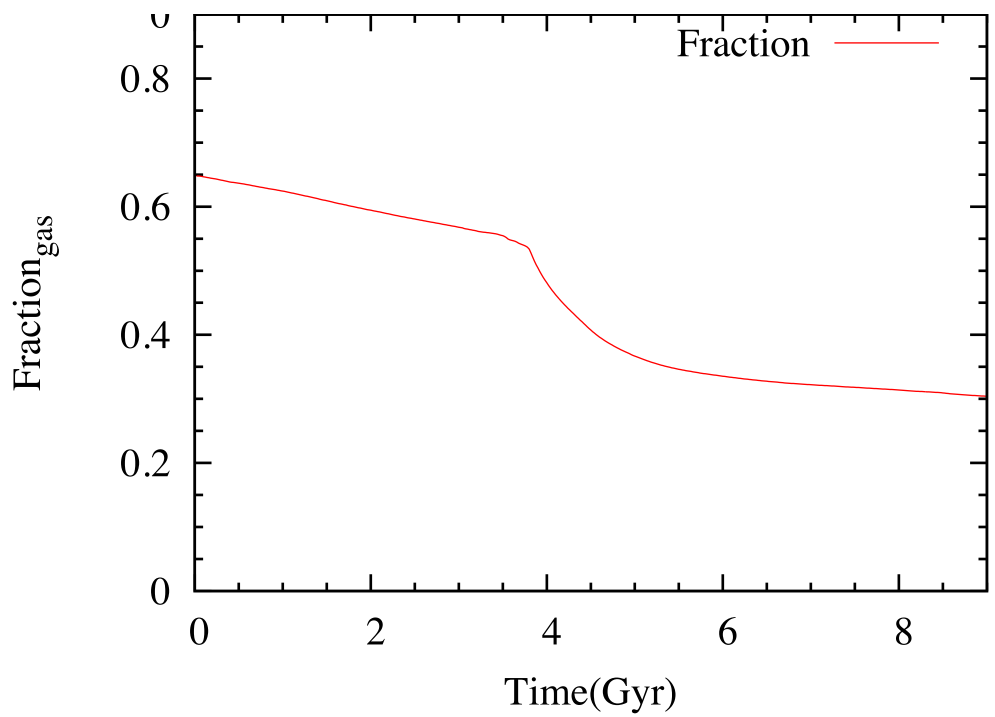
Star formation prescription

Variable feedback adopted

-- high feedback before fusion (3.7Gyr)

-- low feedback after fusion





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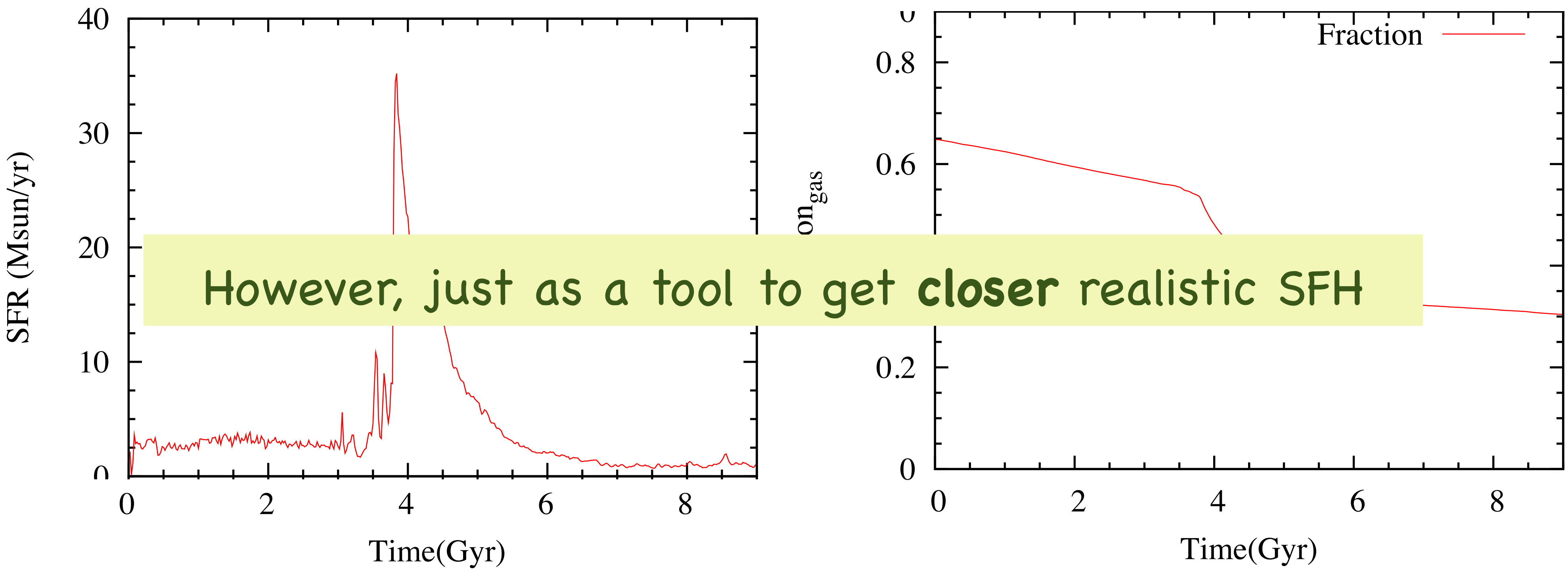

However, just as a tool to get **closer** realistic SFH

results of modeling

- We find a family of model in a certain parameter space explain well the main properties of M31

Ingredient	Tested Range	Comments	Adopted Range
Total mass	$5.5 \times 10^{11} M_{\odot}$	20% of baryons	...
Mass ratio	2–4	To reform $B/T \sim 0.3$	2.5–3.5
$f_{\rm gas}$ Gal1	0.4–0.6	Expected at $z = 1.5$[a]	0.6
$f_{\rm gas}$ Gal2	0.6–0.8	Expected at $z = 1.5$	0.8
Orbit	Near polar	To form the ring	...
Gal1 incy[b]	10–90	Giant Stream	35–75
Gal2 incy[b]	−30 to −110	Giant Stream	−55 to −110
Gal1 incz[c]	90–110	Giant Stream	90–110
Gal2 incz[c]	90–110	Giant Stream	90–110
Spin Gal1	Prograde	...	...
Spin Gal2	Retrograde	Significant remnant disk[d]	...
$r_{\rm pericenter}$	20–30 kpc	See the text	22–30 kpc
Feedback	High-medium[e]	To preserve gas	High/varying[e]
$c_{\rm star}$	0.004[f]–0.03	To preserve gas	0.03

results of modeling

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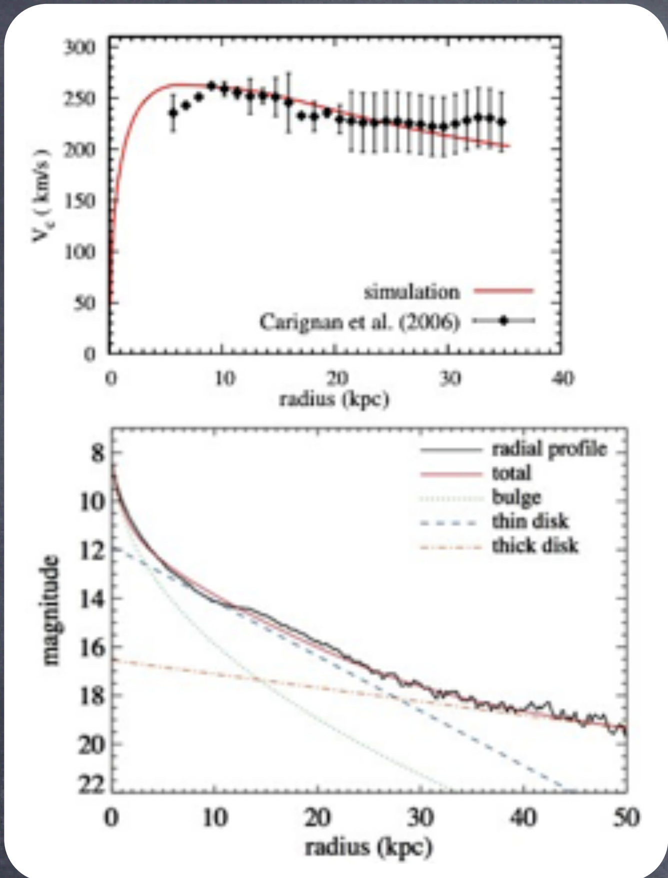
Table 3
Summary of Model Parameters from Table 1 Used throughout the Paper (All within the Range of Parameters of Table 1, Column 4)

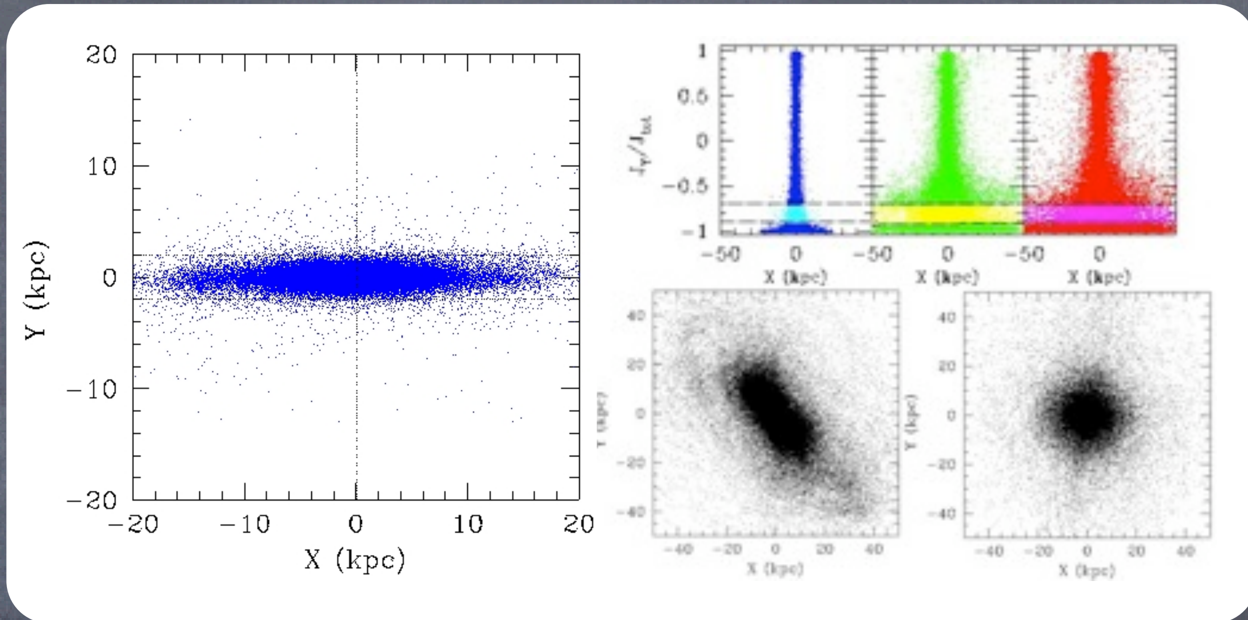
Parameter	Figure 2	Figure 3	Table 2a	Table 2b	Table 2c	Table 2d	Table 2e	Figure 5 & Figure 6(b)	Figure 6(a) & Figure 11(a)	Figure 6(c)	Figure 11(b)
Mass ratio	3.0	2.8	3.5	3.0	2.8	2.5	2.5	3.0	3.0	3.0	2.8
Gal1 incy	70	65	60	65	65	65	65	65	65	65	65
Gal2 incy	−100	−89	−109	−89	−89	−89	−89	−95	−95	−105	−89
Gal1 incz	50	90	110	90	90	90	90	90	85	90	90
Gal2 incz	90	90	110	90	90	90	90	90	85	90	90
$r_{pericenter}$	24	30	24	24.8	24.8	24	24	24.8	24.8	26	30
Feedback	1	1	1	1	1	1	3	3	4	1	1
$N_{particle}$	300	300	154	300	159	300	159	540	540	300	960
M_{DM}	2.2	2.2	7.3	2.2	7.3	2.2	7.3	1.2	1.2	2.2	0.68
$M_{oldstar}$	1.1	1.1	1.8	1.1	1.8	1.1	1.8	0.6	0.6	1.1	0.34
M_{gas}	1.1	1.1	0.9	1.1	0.9	1.1	0.9	0.6	0.6	1.1	0.34
$M_{newstar}$	0.37	0.37	0.3	0.37	0.3	0.37	0.3	0.3	0.3	0.37	0.11
						Model goodness					
Decomposition	OK	OK	OK	OK	OK	OK	NO	OK	OK	OK	OK
Disk scale length	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
10 kpc ring	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Giant Stream	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Stellar ages	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK	OK
Gas fraction	NO[a]	NO[a]	NO[a]	NO[a]	NO[a]	NO[a]	OK	OK	OK	NO[a]	NO[a]

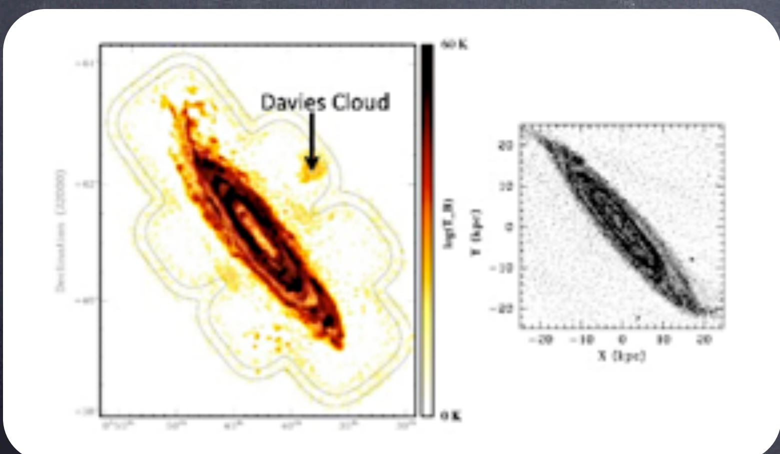
results of modeling

Video of M31 formation

results of modeling







The first-order constraints are matched

Rotation curve

Bulge-to-total mass ratio : B/T = 0.28

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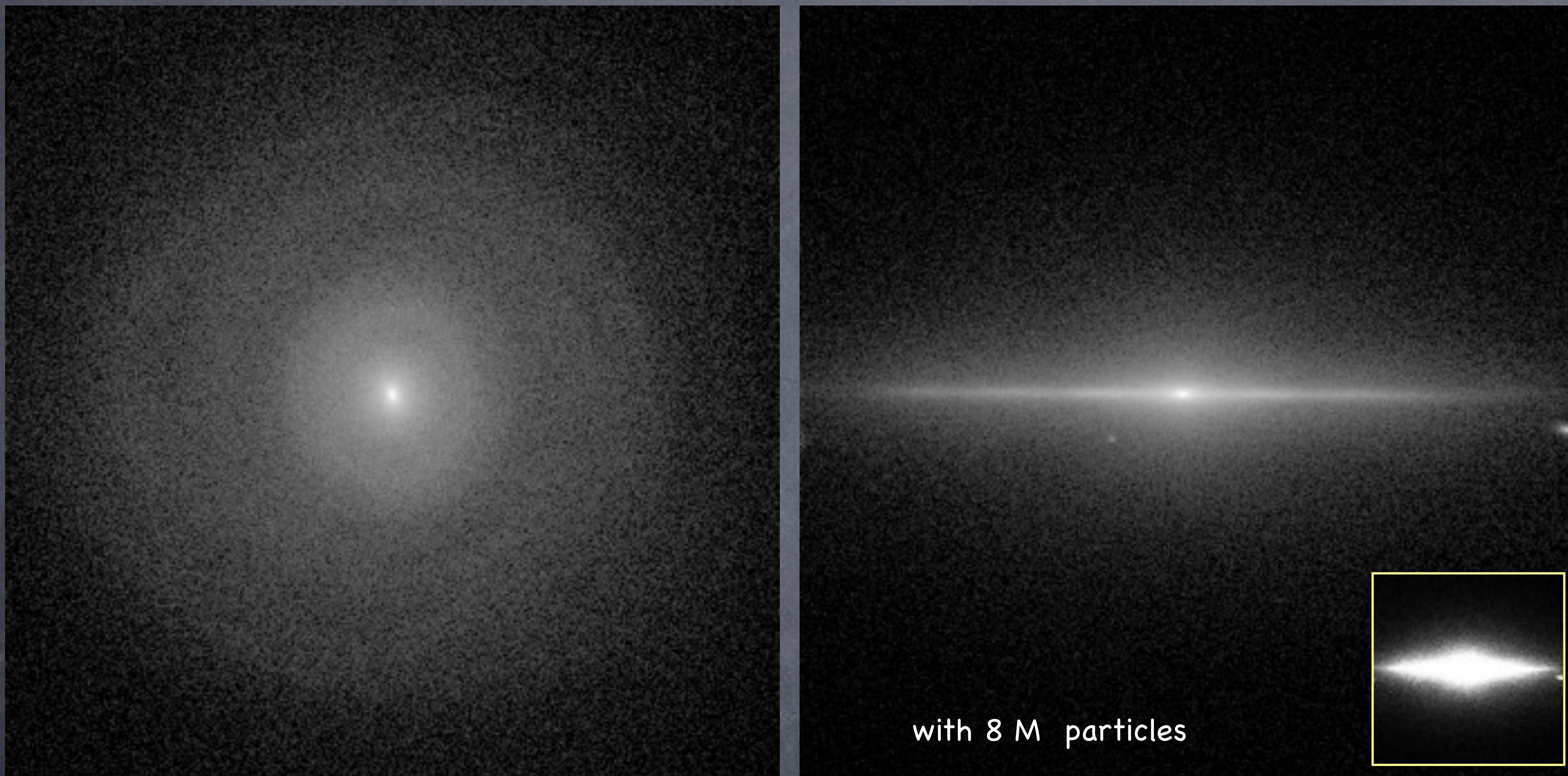
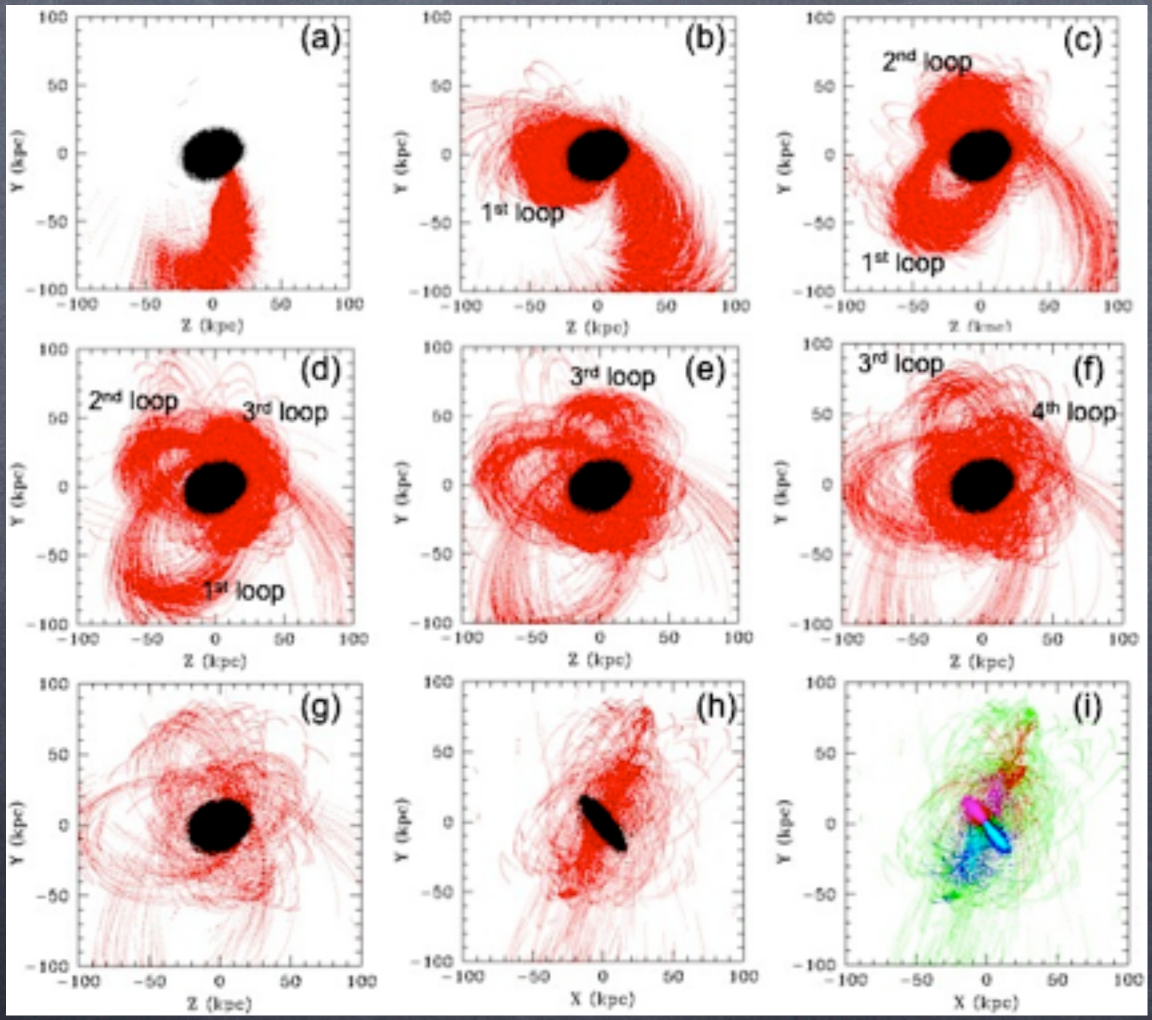
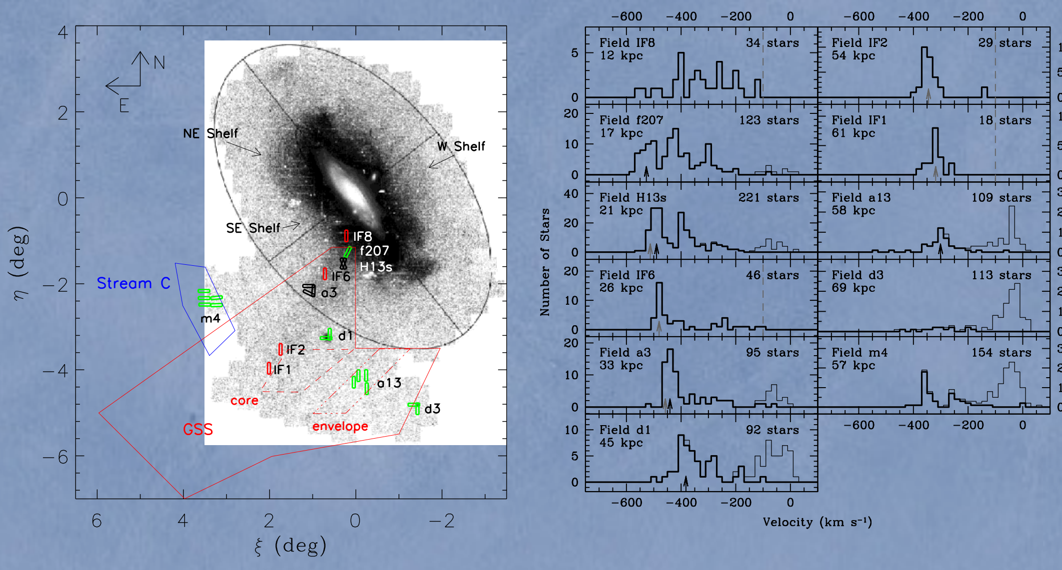

with 8 M particles

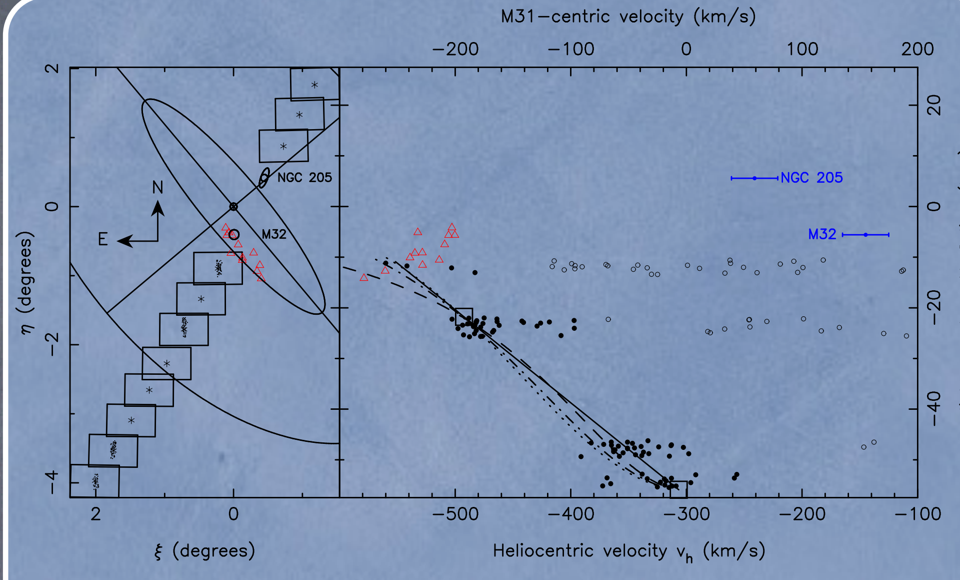
results of modeling

Formation of Giant Stream (with a video)

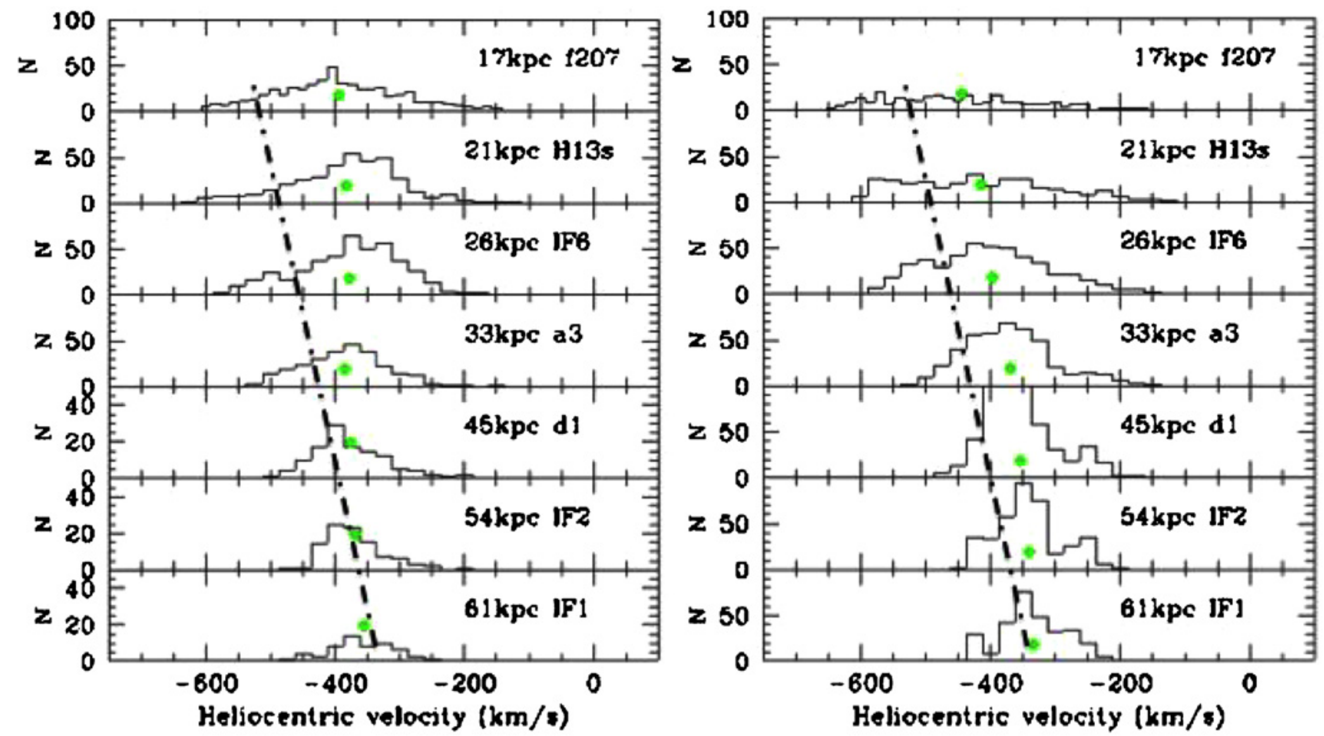




Gilbert et al. (2009)



Ibata et al. (2004)



Conclusion

- The complexities of M31 is well explained by a single event of major merger: morphology (disk+bulge, GS), kinematics, stellar populations.
- Up to 15% baryon matter is ejected from the collision, far to 1 Mpc (see video). This may populate the whole Local group space, possibly including our Milky Way. (--> LMC story)

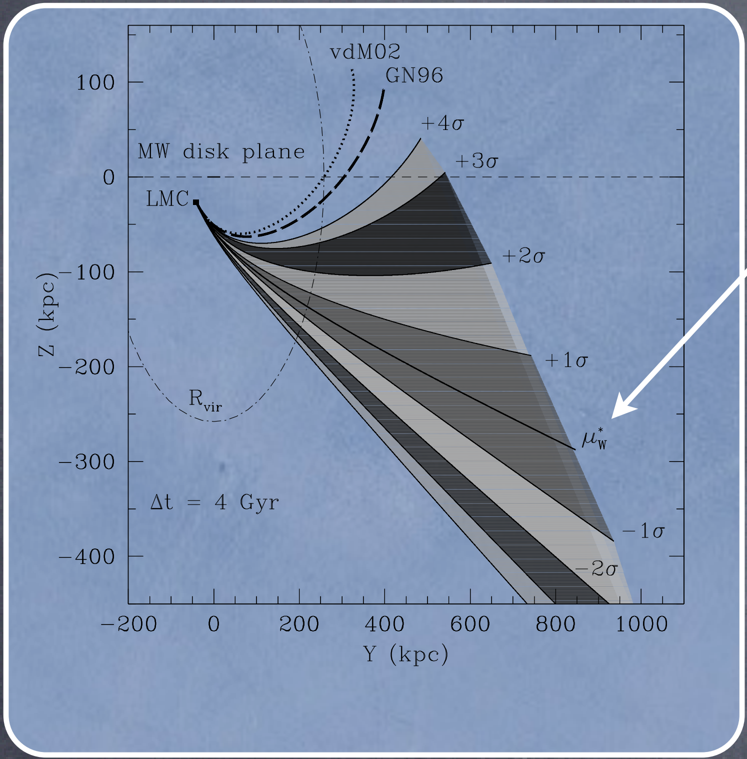
Origin of Magellanic clouds (MC)

Could the Magellanic Clouds be Tidal Dwarfs Expelled from a Past-merger Event Occurring in Andromeda?

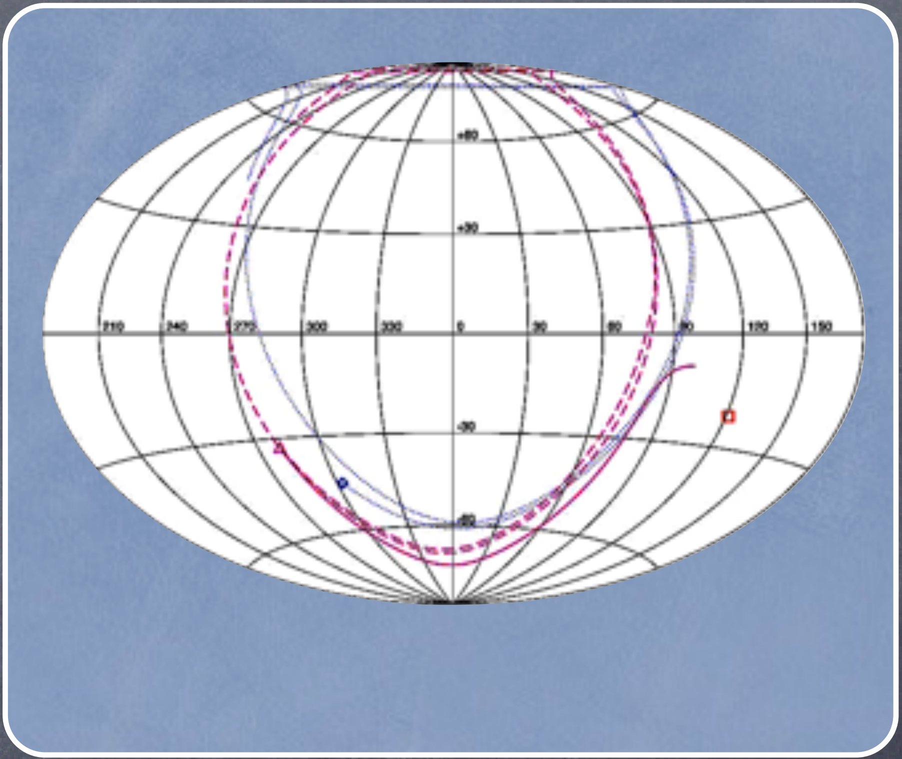
Evidences for alien

- high space velocity, 380 km/s, close to escape velocity of Milky Way At r=50 kpc.
- MCs are the only blue satellite near the Milky Way
- Besla, 2007, propose the first passage scenario of MC.

Trace back in time



Besla et al. 2007



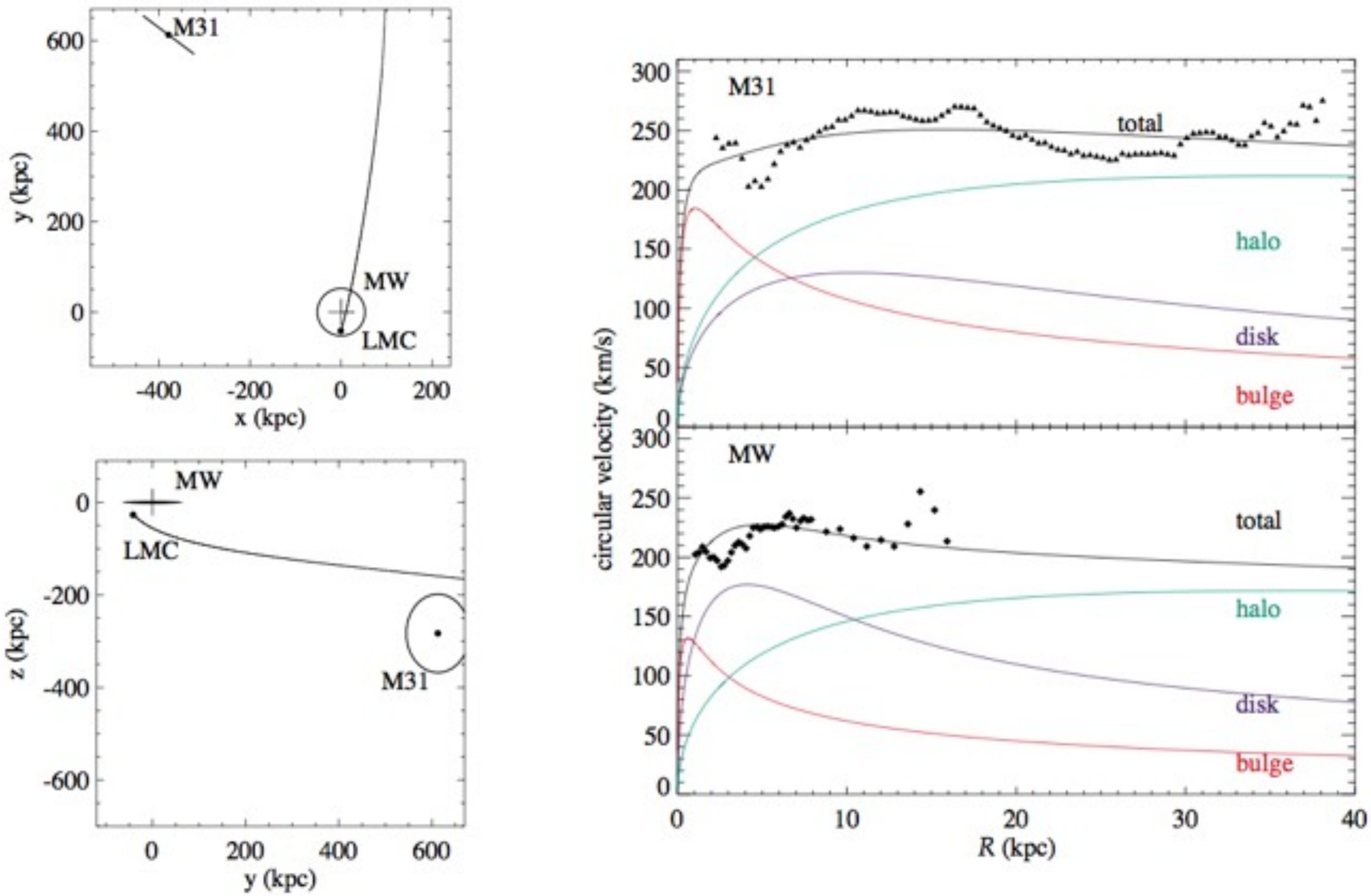
Kallivayalil et al. 2009

M31 proper motion = 0, 42 km/s
(cf. van der Marel et al. 2008)

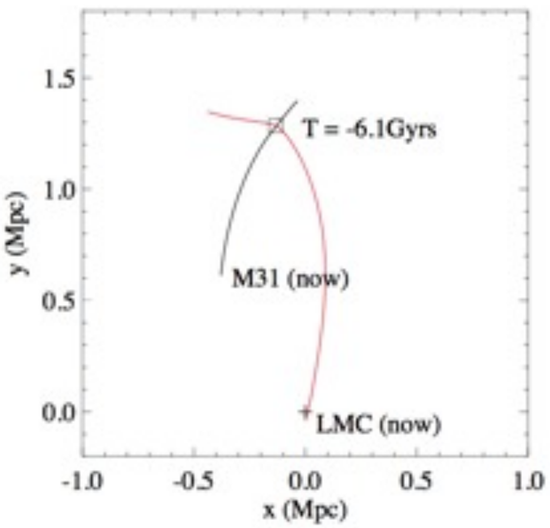
possibility MC is from M31

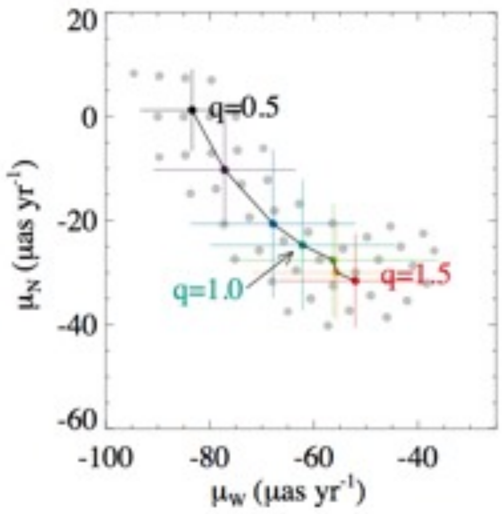
- Previous studies: Raychaudhury & Lynden-Bell 1989, Byrd et al. 1994, Shuter 1992
- In a major merger, the matter ejected mainly close the plane of orbit.
- M31 edge-on (Inc. 77 deg), MW may be include.
- no direct measure for M31 proper motion! (can be expected from GAIA)

Three body model



results





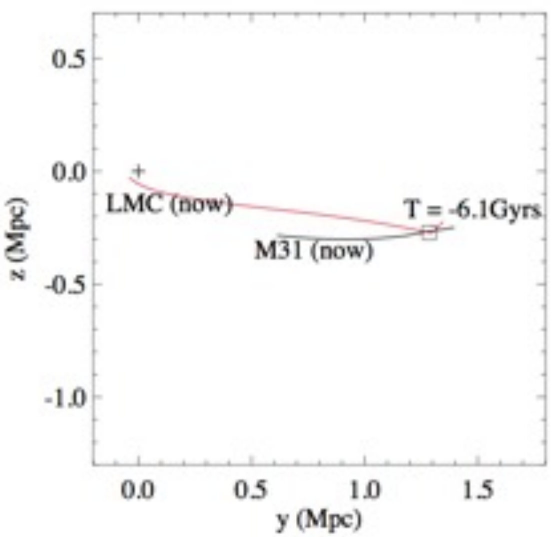


Table 3
Possible Solutions

q^{a}	μ_W	μ_N	v_{rad} [b]	v_{tan} [b,c]	T_{travel}	v_{50} [d]
	(μas yr^{-1})		(km s^{-1})	(km s^{-1})	(Gyr)	(km s^{-1})
0.5	-83 ± 10	01 ± 08	-127	194 ± 44	-4.3 ± 0.5	432
0.7	-77 ± 14	-10 ± 10	-128	160 ± 56	-4.5 ± 0.6	428
0.9	-68 ± 16	-21 ± 14	-128	124 ± 53	-5.1 ± 1.1	423
1.0	-62 ± 18	-25 ± 13	-128	106 ± 63	-5.5 ± 1.4	421
1.1	-56 ± 20	-28 ± 11	-129	89 ± 68	-6.2 ± 1.9	418
1.3	-56 ± 16	-30 ± 09	-129	89 ± 48	-7.8 ± 2.2	417
1.5	-52 ± 15	-32 ± 09	-129	80 ± 46	-7.2 ± 2.3	417

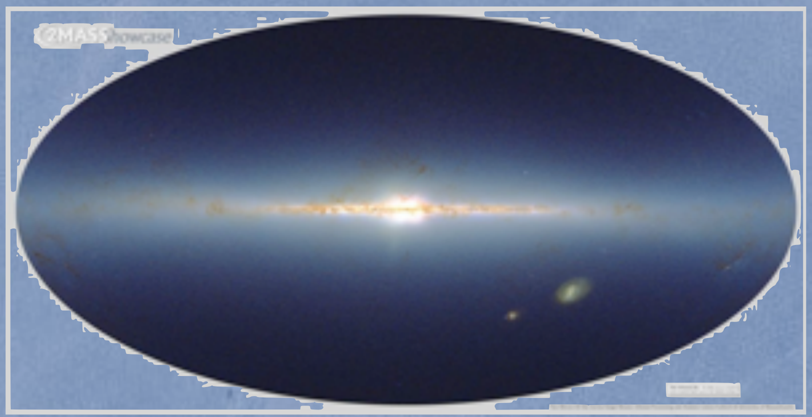
Conclusion

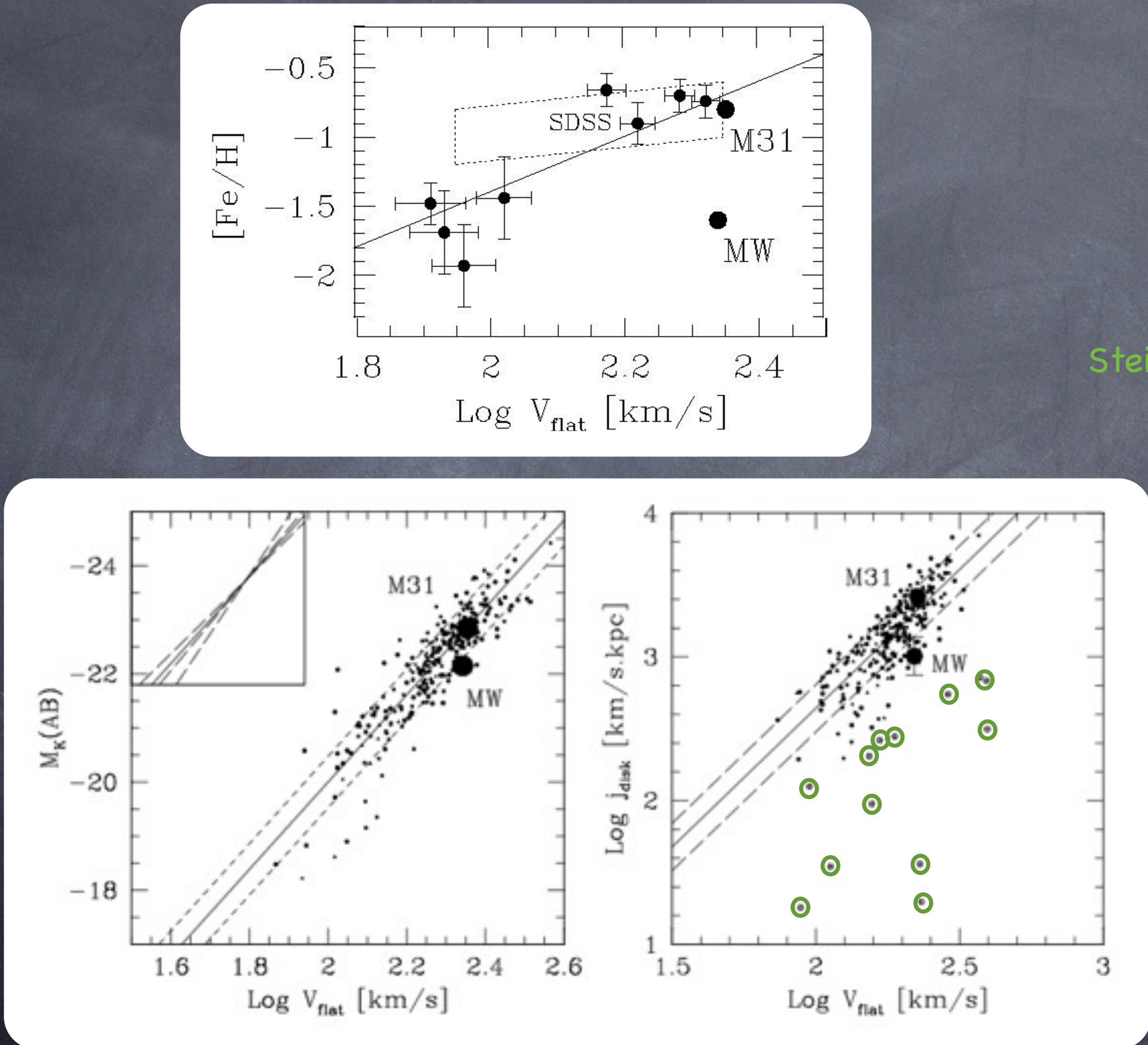
- Both observation and calculation indicate the possibility that MCs could be originated from M31.
- GAIA will provide the direct determination of M31 proper motion, which will support or decline the validity the scenario.

Monday, 21 March 2011

Could Milky Way be formed by major merger?

B/T = 0.19
thick disk ~ 10% of thin disk
R(thin disk)=2.3+/-0.5 kpc
R(thick disk)=3.0 kpc
Baryon mass = 5.5 10^10 Msun
gas fraction = 12%





Hammer et al. 2007

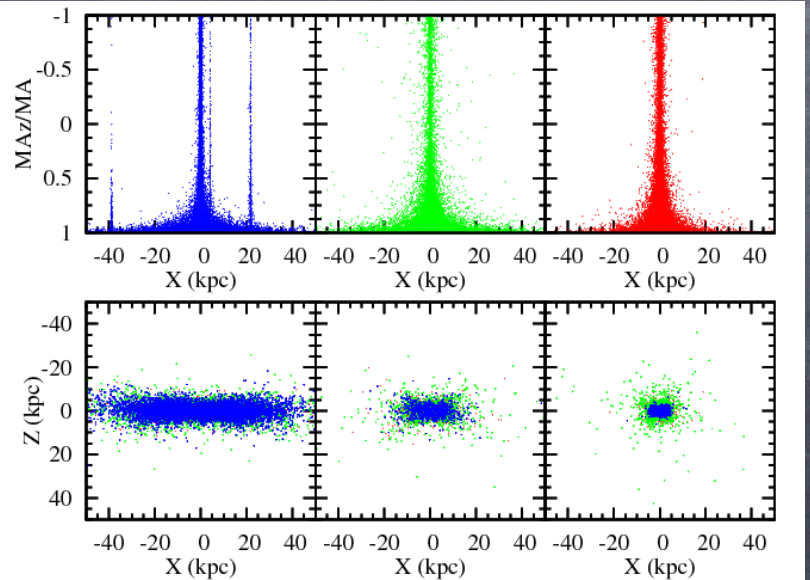
Steinmetz&Navarro.1999

Evidences of major merger

- age, metallicity of thick disk and bulge are comparable. (this is predicted by major merger)
- thick disk has stars older than thin disk.
- possible presence of a classical bulge in the MW. (Babusiaux et a.2010)

first try (J.L. WANG et al.)

Shrink stellar disk by 5.8 factor (steidel 2011, <z>=2.65)
Mass ratio 3
Gas fraction 80%
Dark matter fraction 80%
Pericenter 18 kpc
Star formation history: 5 median feedback before fusion + very low feedback after fusion



	thin disk	thick disk	bulge	sum
star	2.33 (0.55)	0.21 (0.05)	1.67 (0.40)	4.22
gas	1.16 (0.97)	0.02 (0.01)	0.02 (0.02)	1.20
total	3.50 (0.65)	0.23 (0.04)	1.69 (0.31)	5.42

+video