Reproducing properties of MW dSphs as descendants of DM-free TDGs

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[1]Paris Observarory/Meudon, [2]Case Western Reseve University, USA, [3]HISKP Bon university

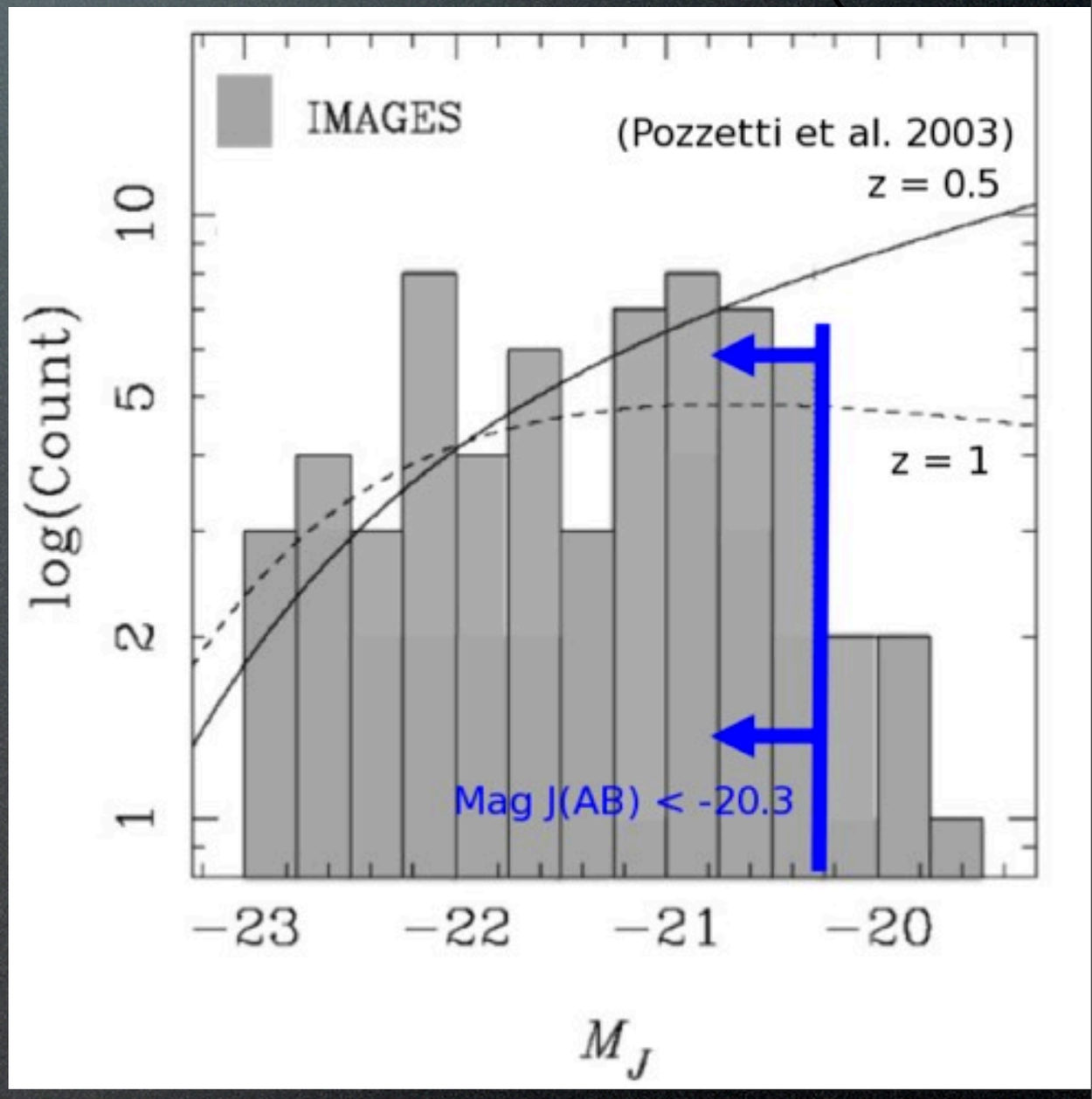
Content

- Disk rebuilding (IMAGES, large VLT program)
- The Local Group
- M31 : a major merger result & its impact
- Distribution of MW satellites
- TDG origin of MW satellites
- Conclusion

IMAGES (Intermediate MAss Galaxy Evolution Sequence)

Hammer 2005; Flores et al. 2006; Puech et al. 2007; Yang et al. 2008;
Neichel et al. 2008; Rodrigues et al. 2008; Puech et al. 2008; Peirani+08;
Hammer et al. 2009; Yang+09; Delgado et al. 2010,Fuentes-Carrera+10

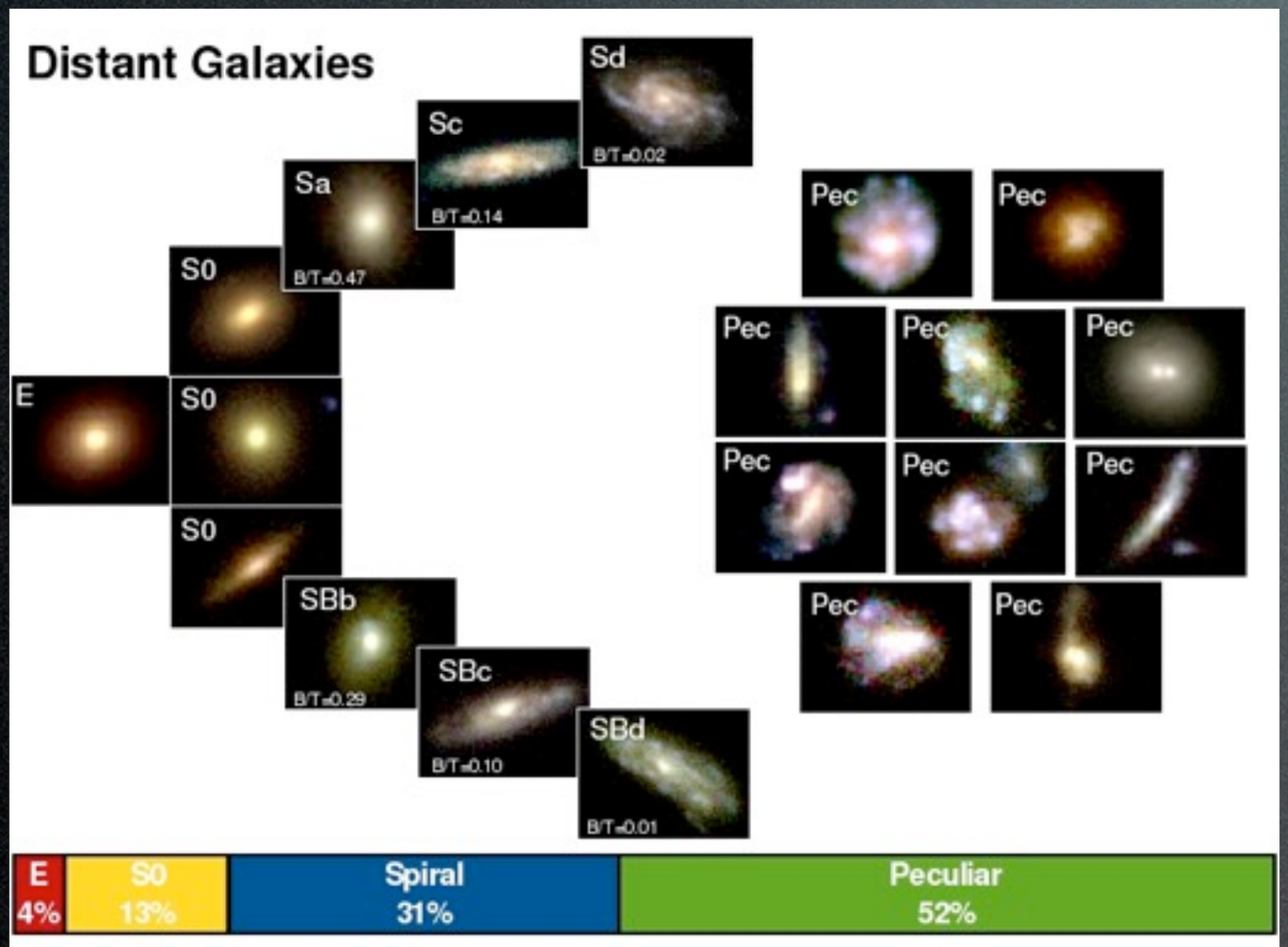
- 63 emission line galaxies
  (M_J < -20.3), (Mass > 1.5x10^10Msun)
- redshifts at 0.6
  (0.4 < z < 0.75) , (6 - 8 Gyr)
- Observations
  - spatially resolved kinematics maps with GIRAFFE IFU/VLT
  - morphology with GOODS/HST
  - metallicity with FORS/VLT
  - UV from GALEX
  - IR from IRAC / 24-mu Spitzer



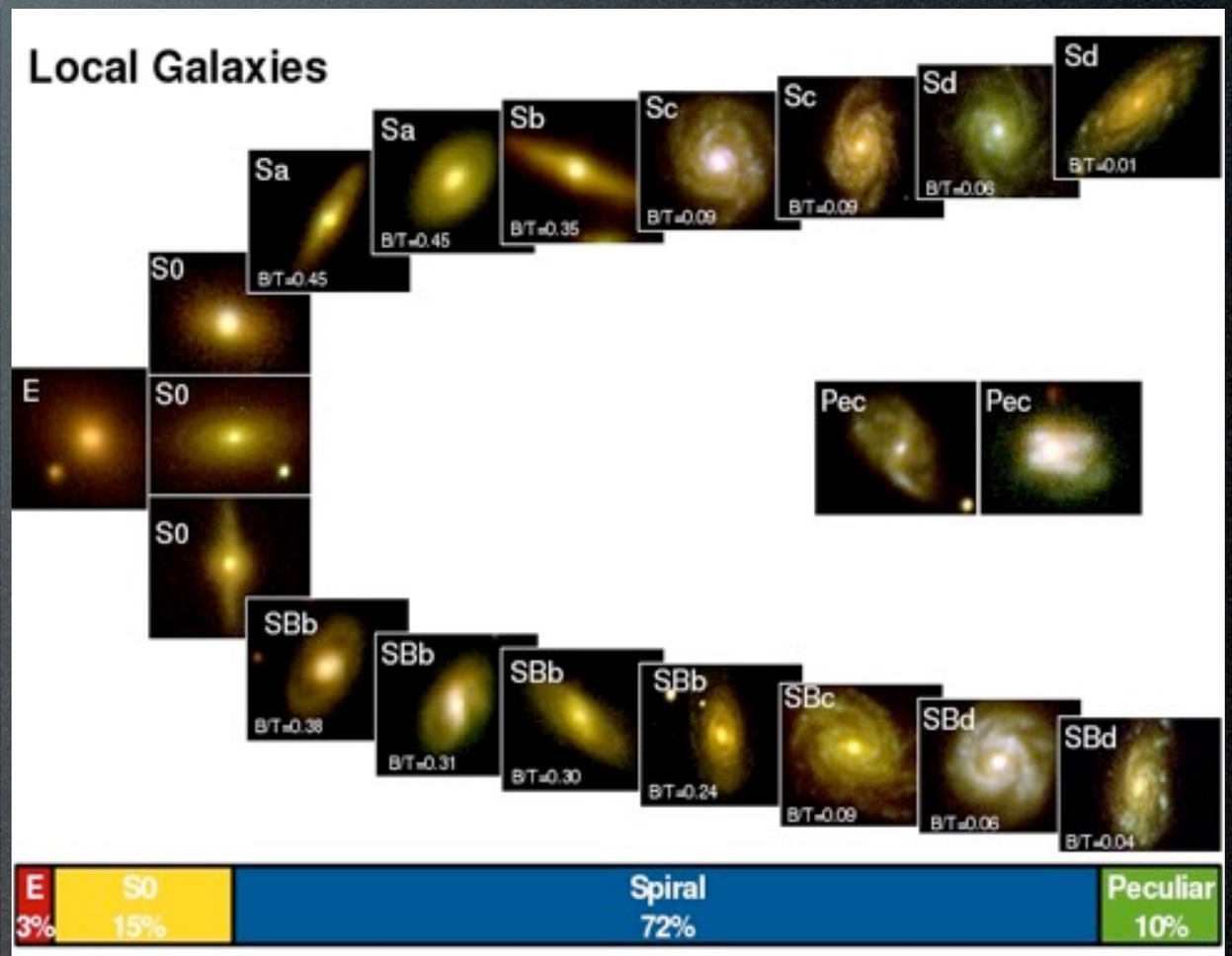
Yang et al. 2008, A&A

IMAGES: Morphology evolution at two epochs

z = 0.65 (6-8 Gyr ago)



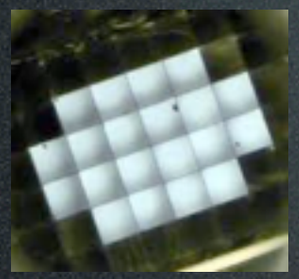
z = 0



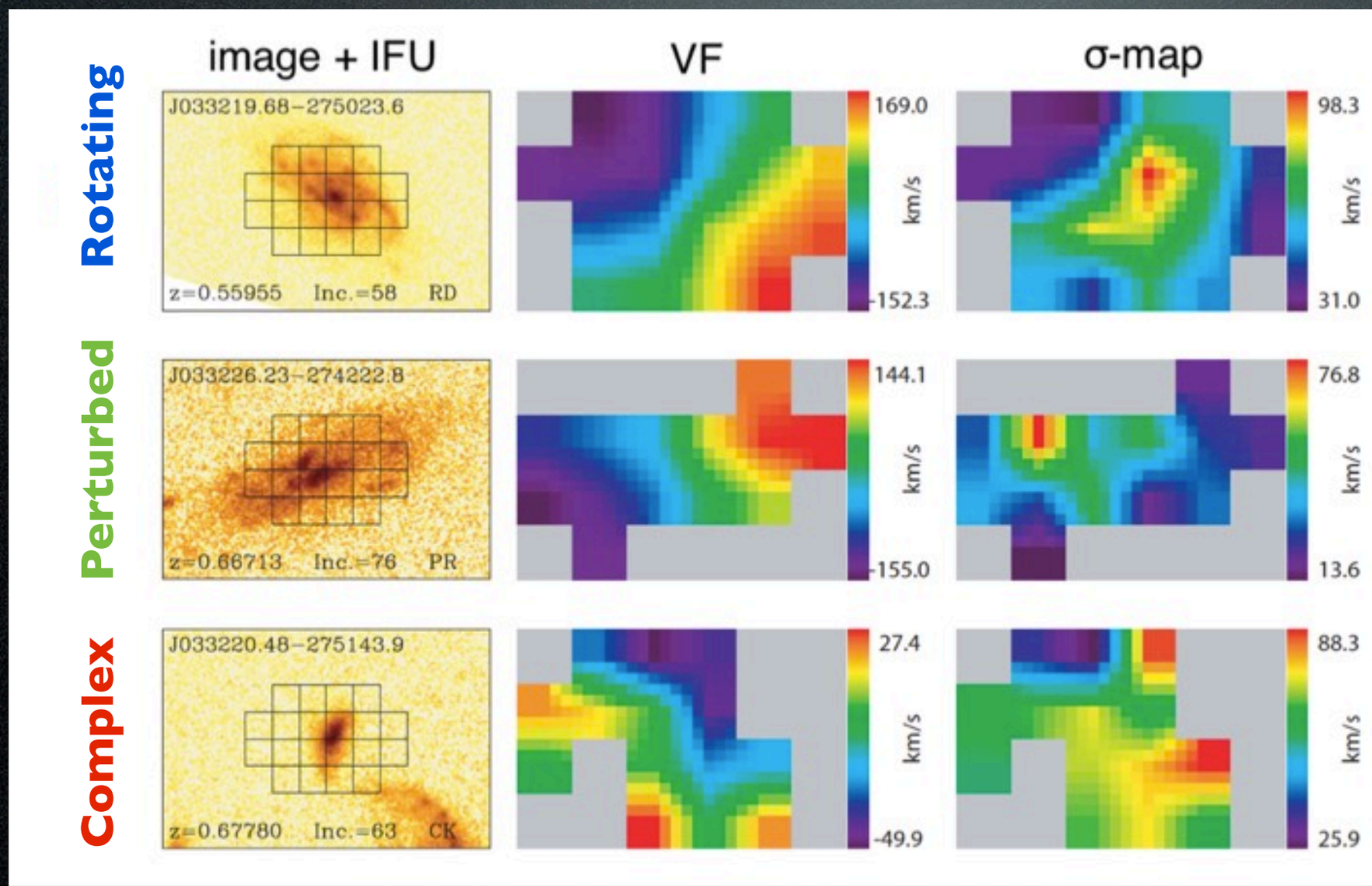
-E/S0 were mostly in place
-Half of spirals did not.

Delgado et al. 2010

IMAGES: kinematics of ionized gas of the 63 galaxies



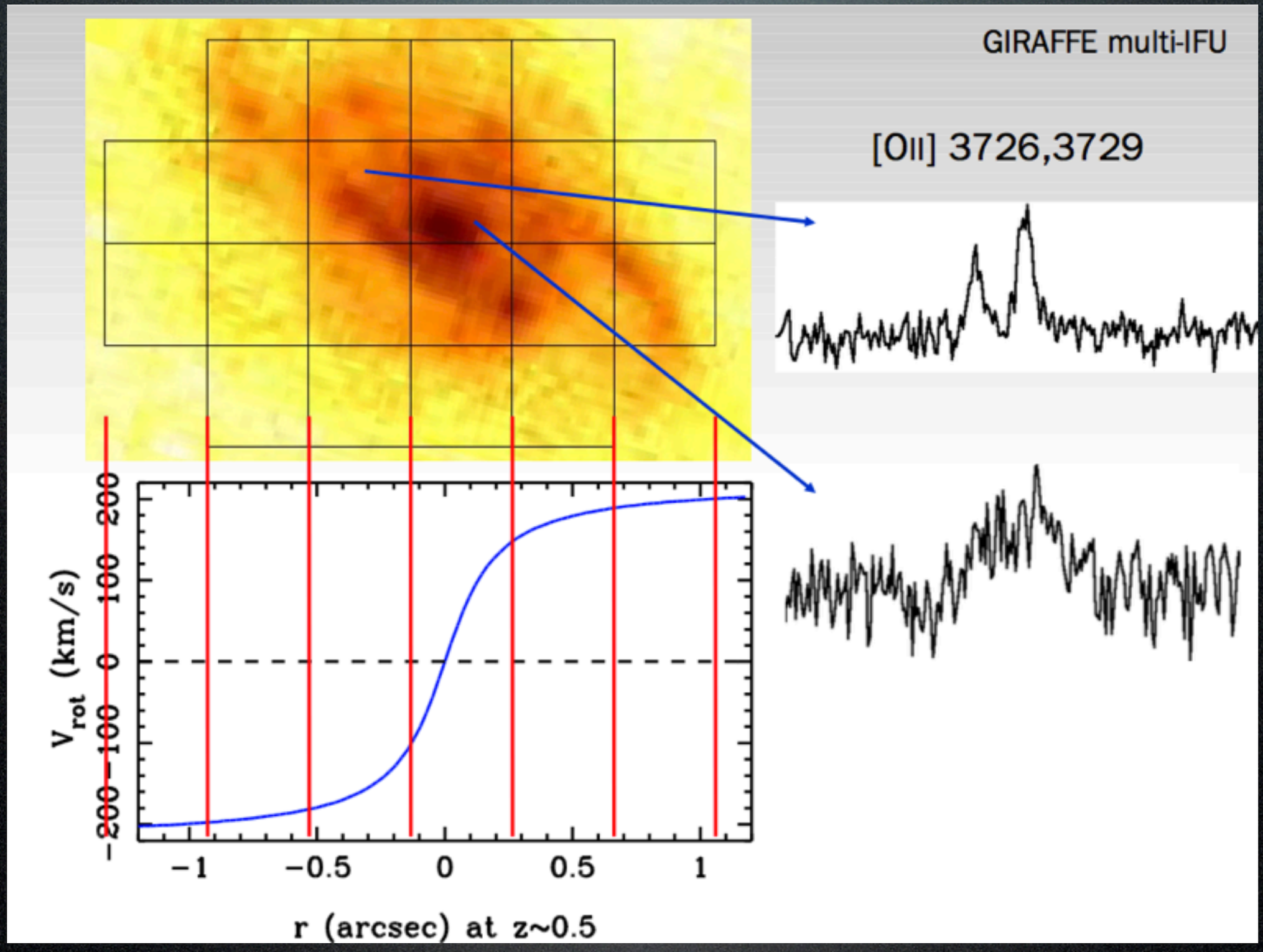
2"x3" IFU, GIRAFFE/FLAMES@VLT



Fraction (+/- 12%)
32%
25%
43%

Flores et al. 2006
Yang et al. 2008, A&A

Identify a rotating disk



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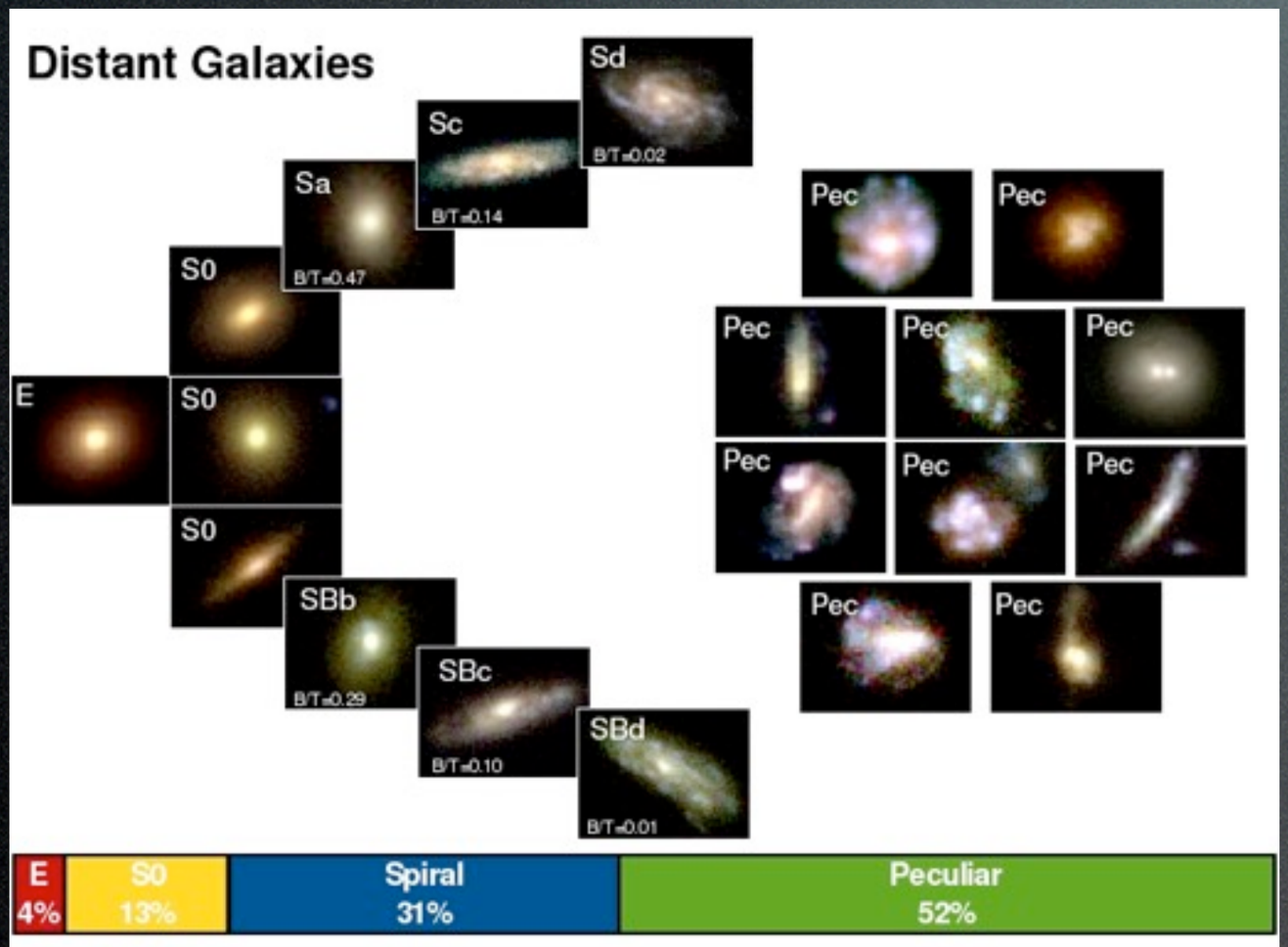
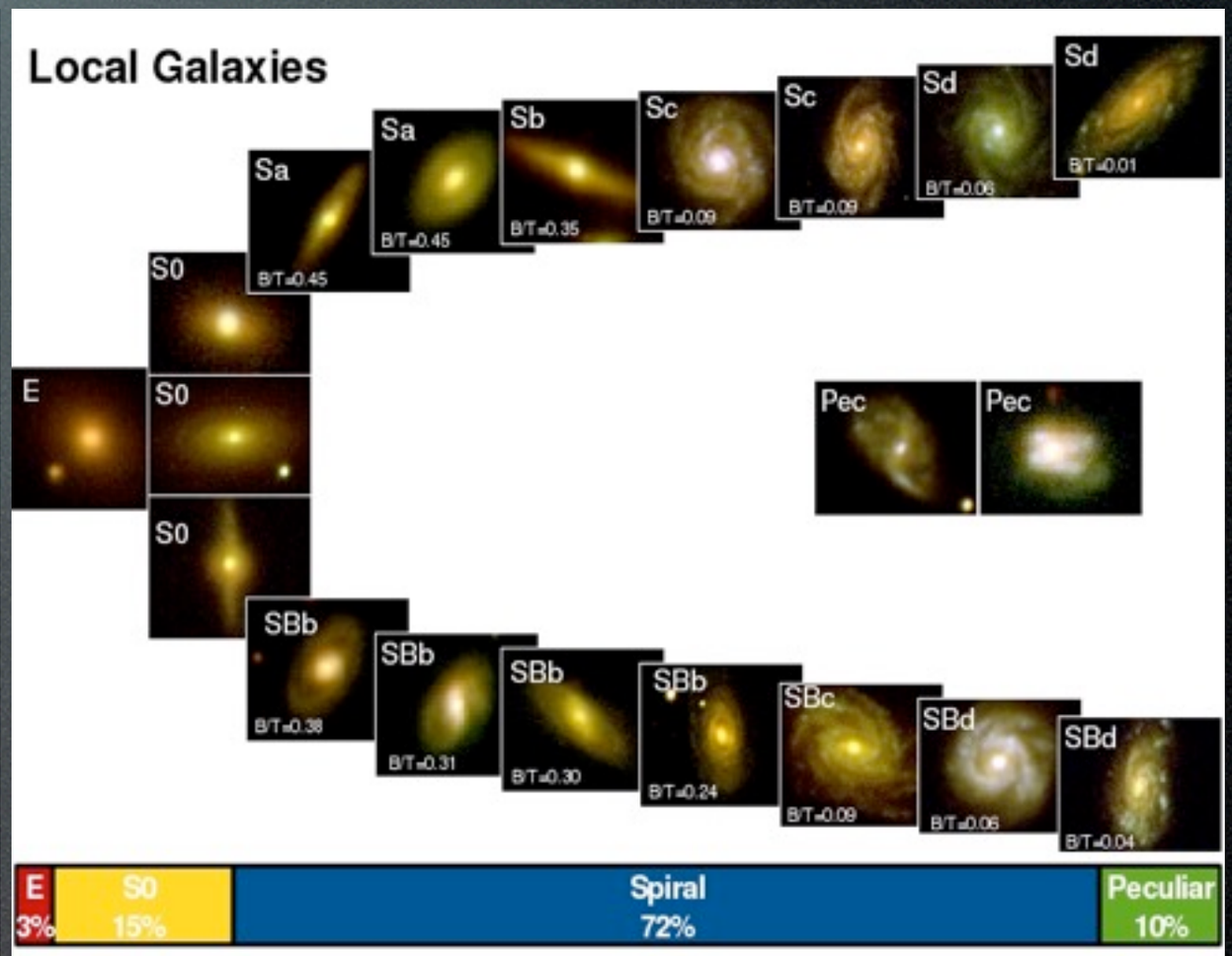


z = 0



Rotating **Perturbed**

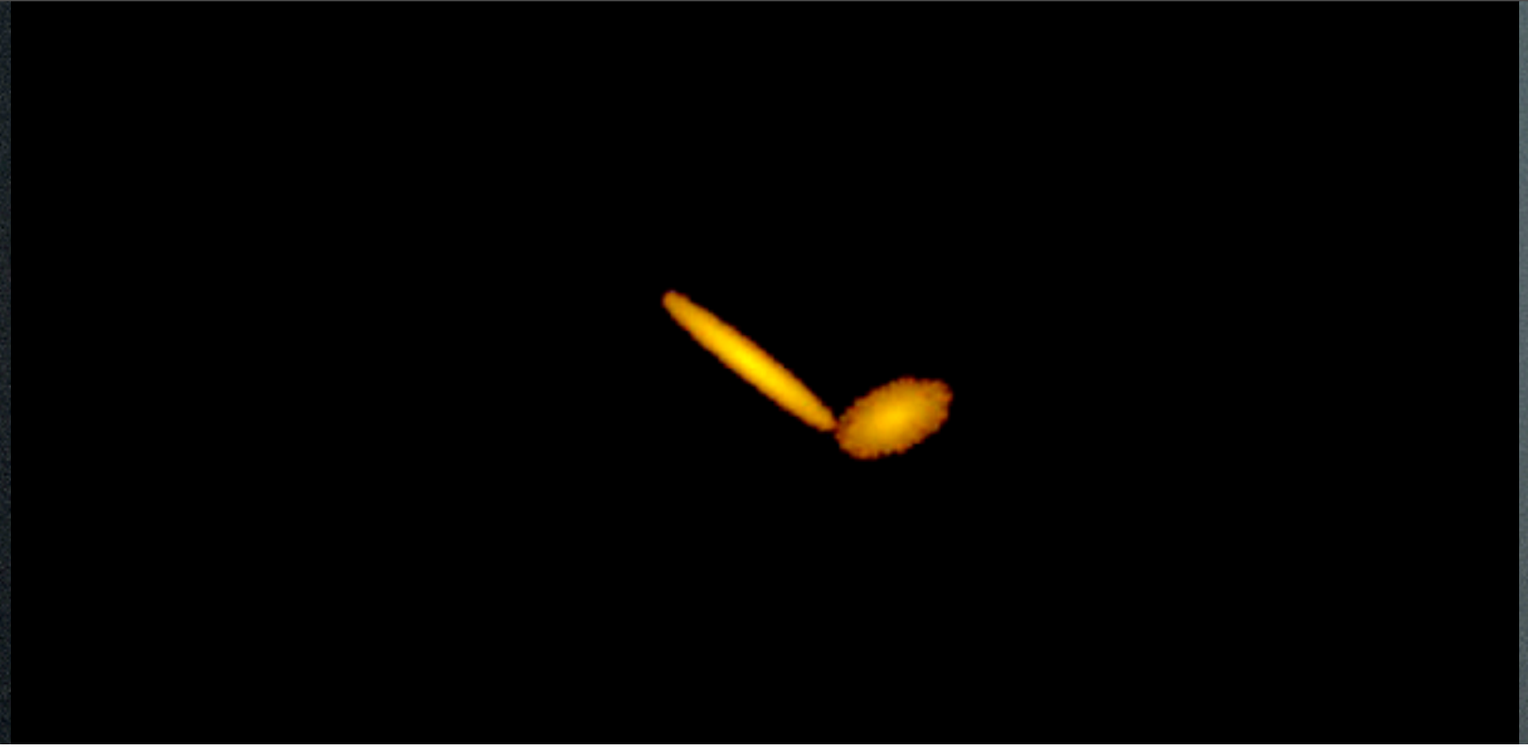
Complex

Neichel et al. 2008

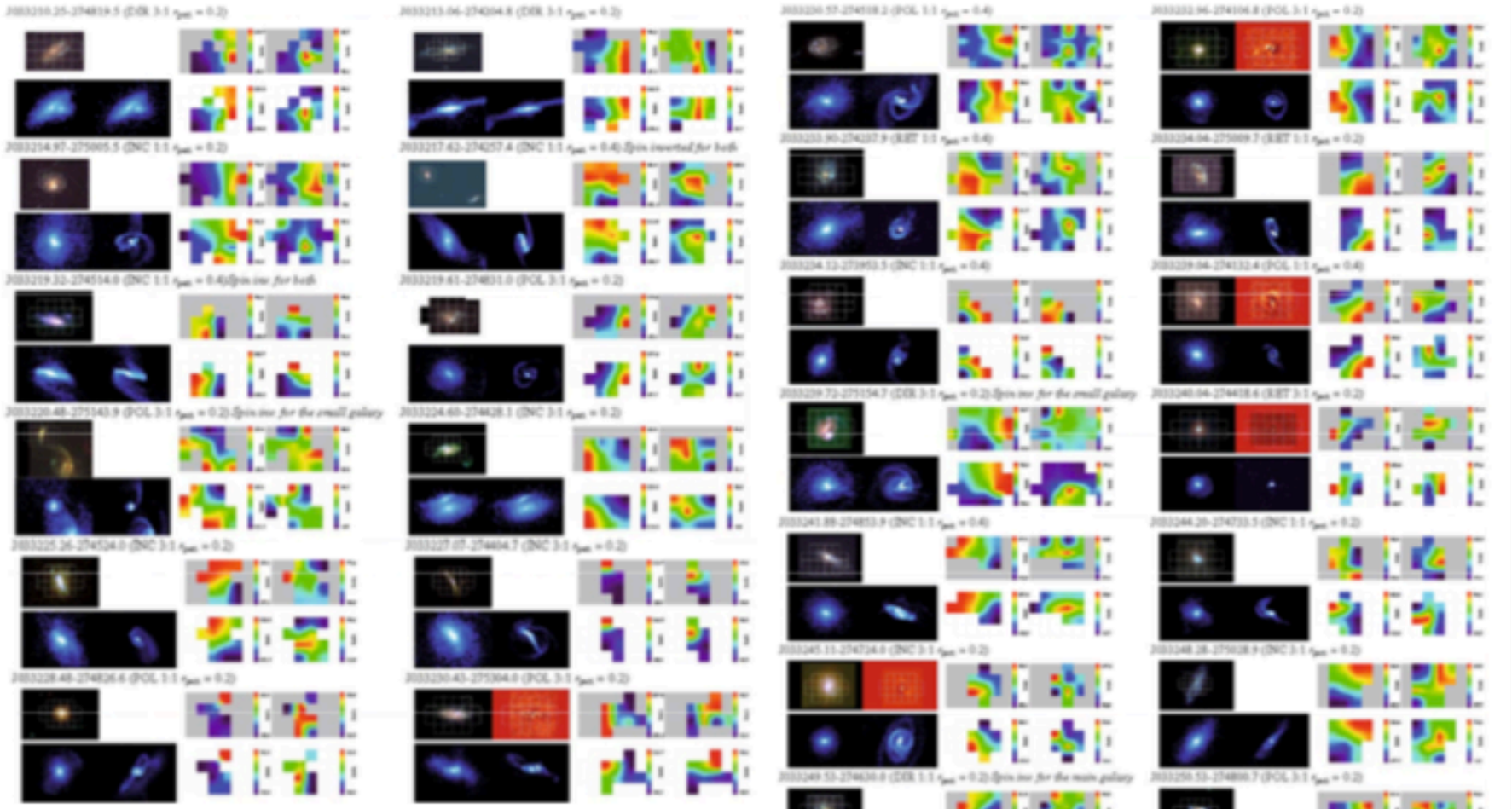
Associating Morpho-kinematics with physical processes

22nd October 2014 Sino-French Workshop, LIA Origins Beijing

Hammer et al. 2009

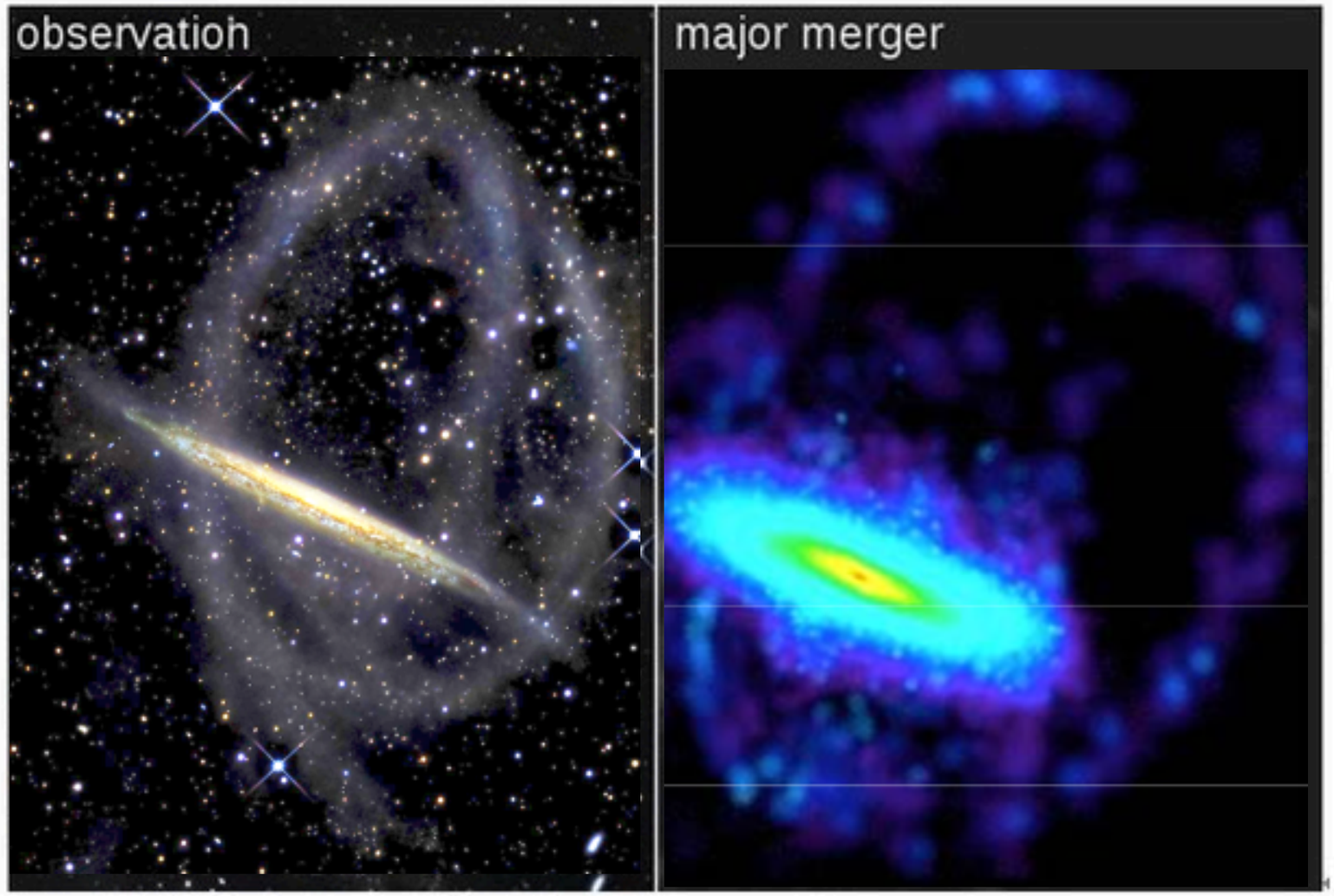


2/3 of non (or semi-)relaxed galaxies have « secured » merger models



Hammer et al. 2009

20% baryon



比较观测的 NGC5907（左图）与模拟的模型（右图）。两张图都展示出侧向的盘以及巨大的老年恒星环，而老年恒星环是过去发生的宏大碰撞的证据。

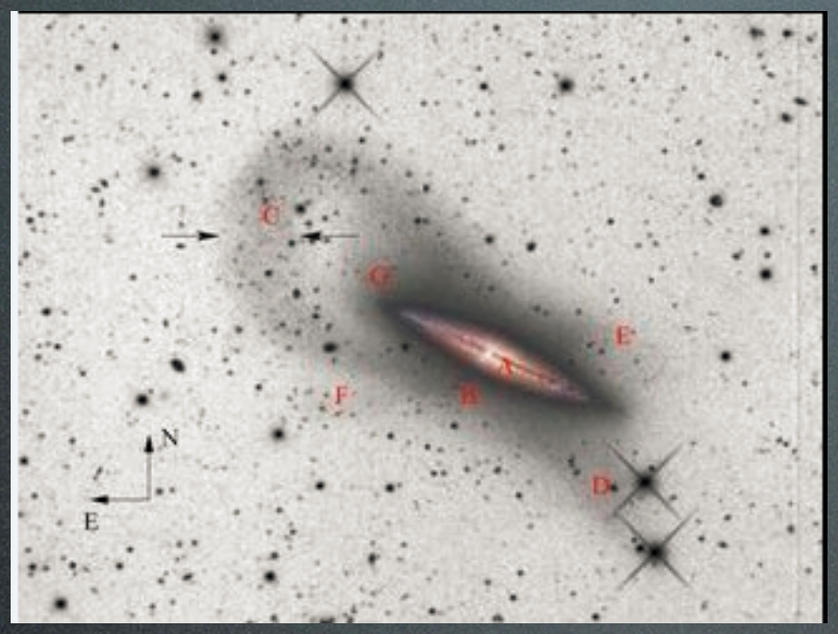
Wang et al. 2012

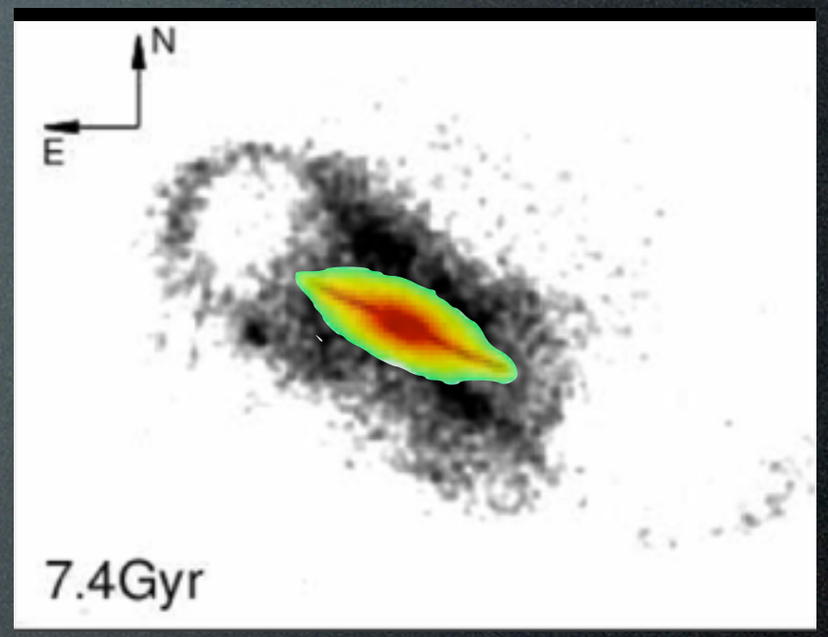
NGC 4013

Observation

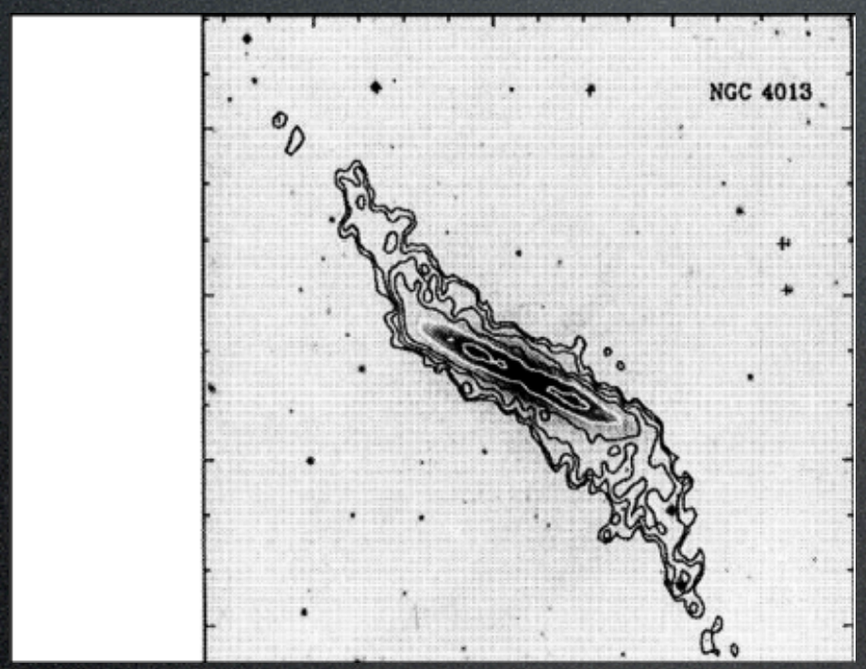
Major merger

Star





HI



Wang et al. 2015

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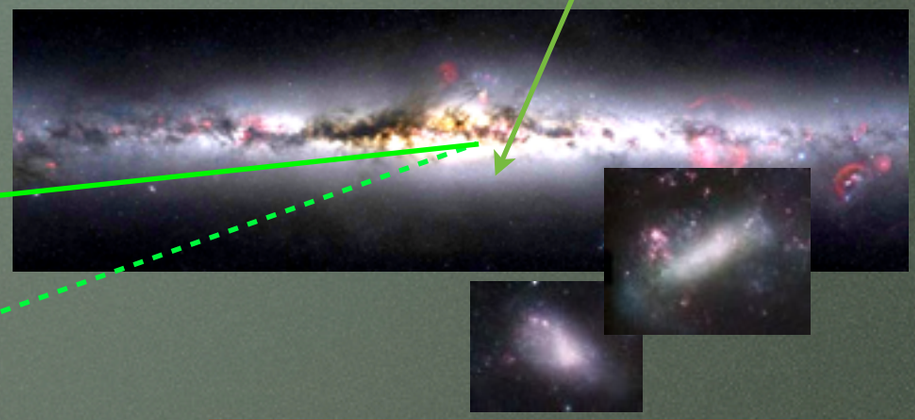
The Local Group

The Sun



$(l,b)=(121, -21.5)$

IC10

780 kpc

M32
M33
And 1,2
... ...

dIrr, dTrans
Phenix
WLM
NGC 300
.....

dwarf spheroidals (classical)

Leo I
LeoII
Fornax
Darco
Sextans

Sculptor
Carina
UMi
Sagittraius

ultra-faint dwarf spheroidals
(SDSS and DES)

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... ...

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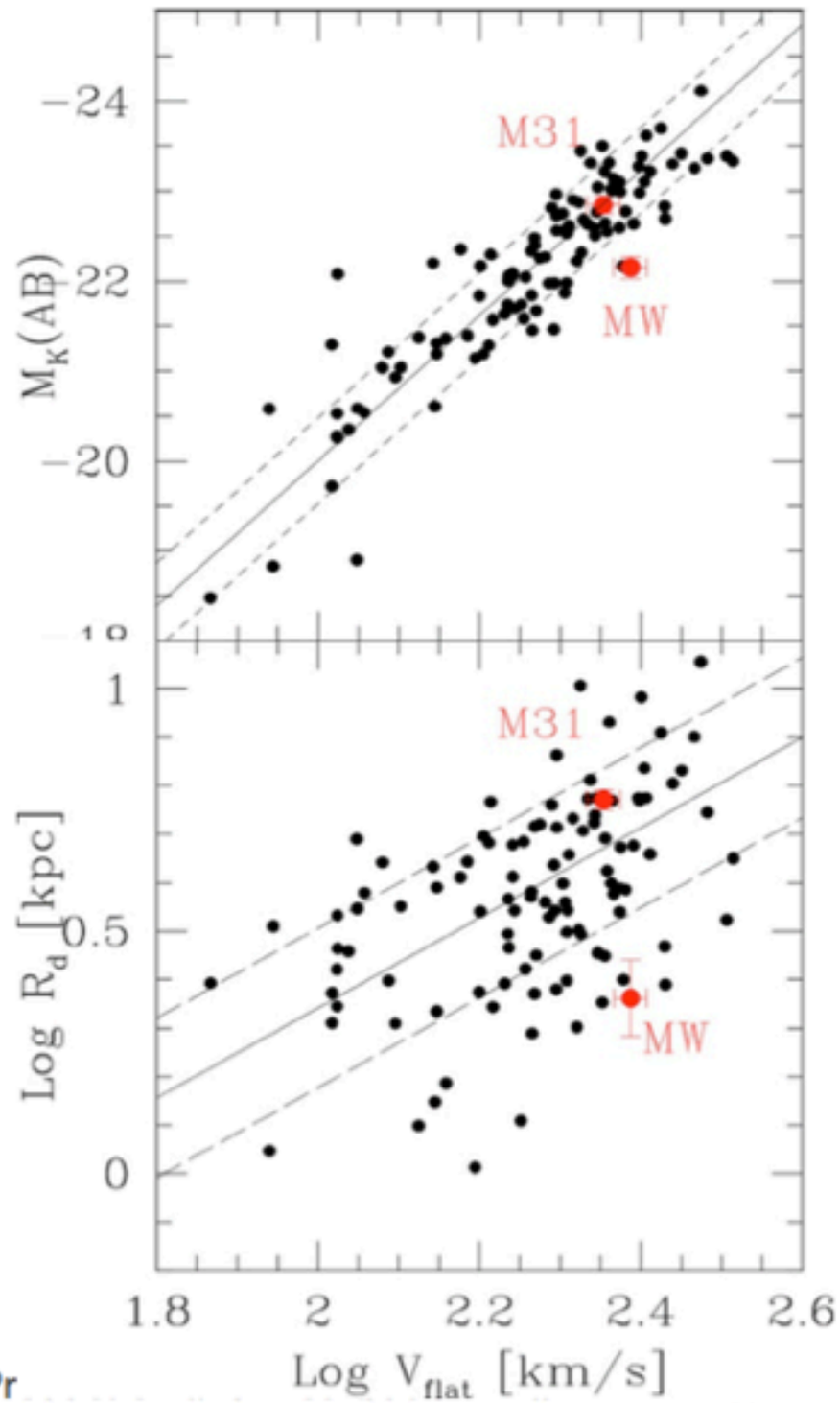
The Milky Way versus M31 and other spirals

Hammer et al. 2007, ApJ, 662, 322

Accurate measurements for the MW and M31:

M_K & R_{disk} (COBE/DIRBE, Hipparcos…) with V_{flat}(MW)=244km/s from Reid et al. (2009) and Bovy, Hogg & Rix (2010)



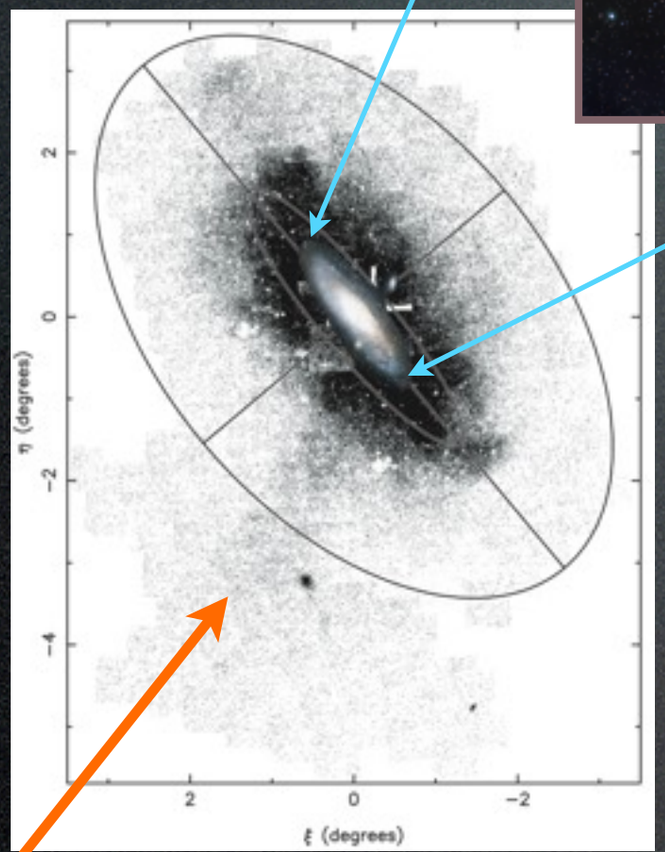
Compared to other spirals (SDSS):

- the MW has a too small stellar mass, radius & angular momentum;
- **M31 is rather typical.**

In the (M_K, R_{disk}, V_{flat}) volume, there are only ~ 1-2% of Milky Way-like galaxies.

Andromeda galaxy (M31)

Classical bulge indicatif of major merger origin

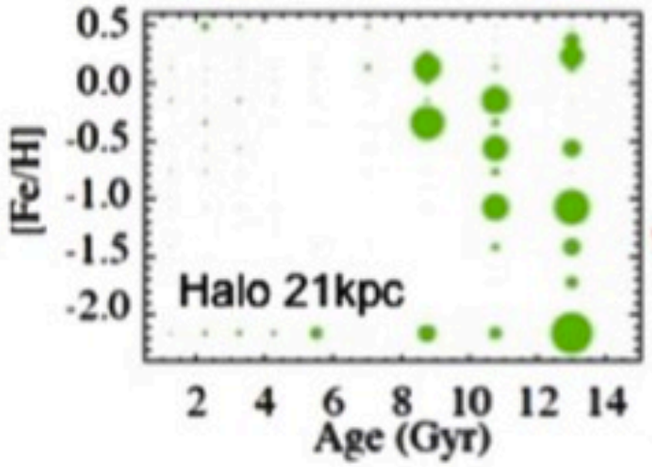


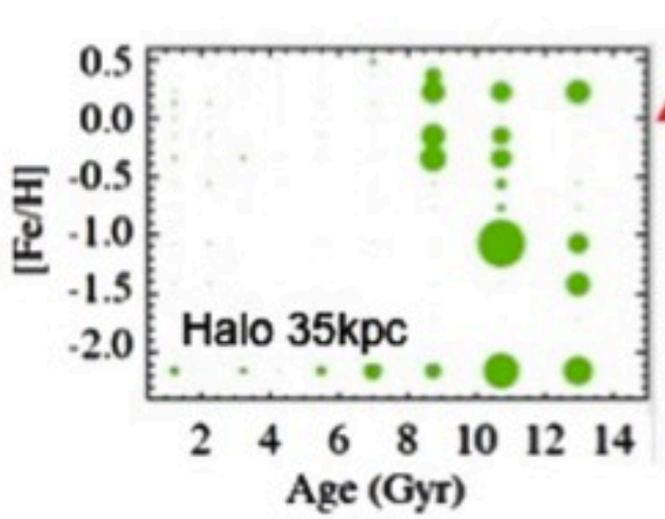
Giant Stream

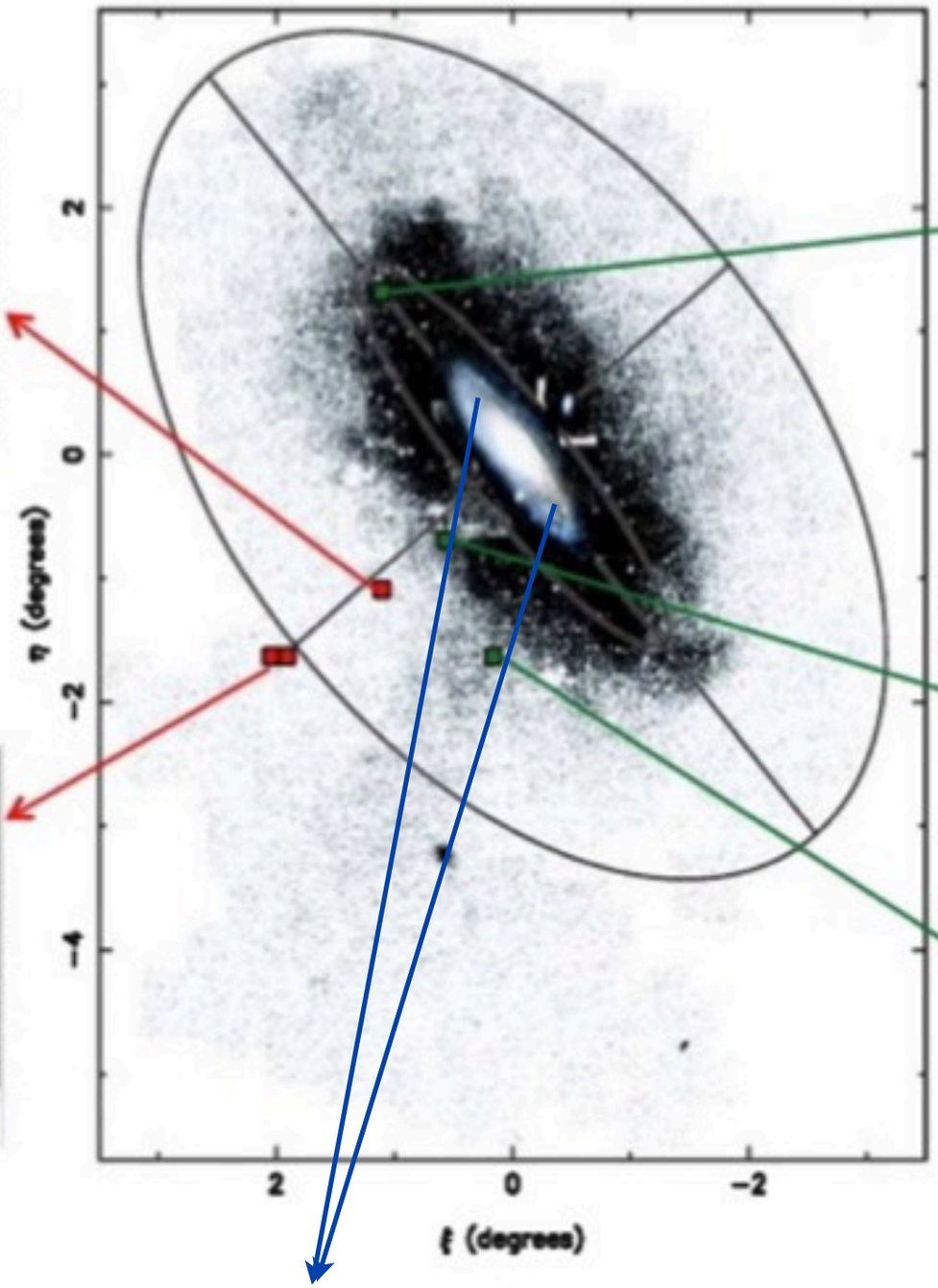
Ibata+2005

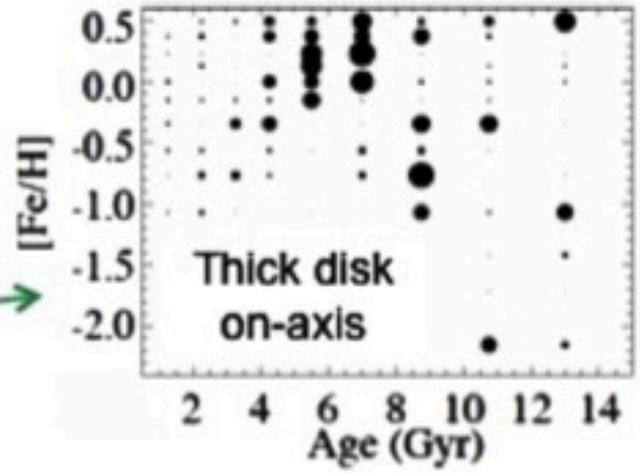
PandAS McConachie+2009 with CFHT

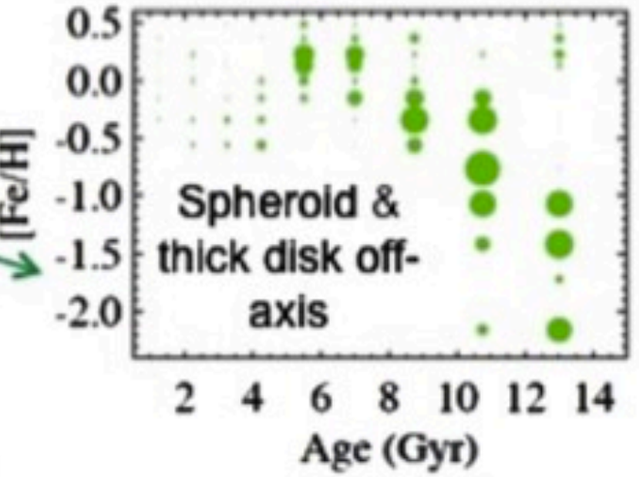
>8.5Gyr

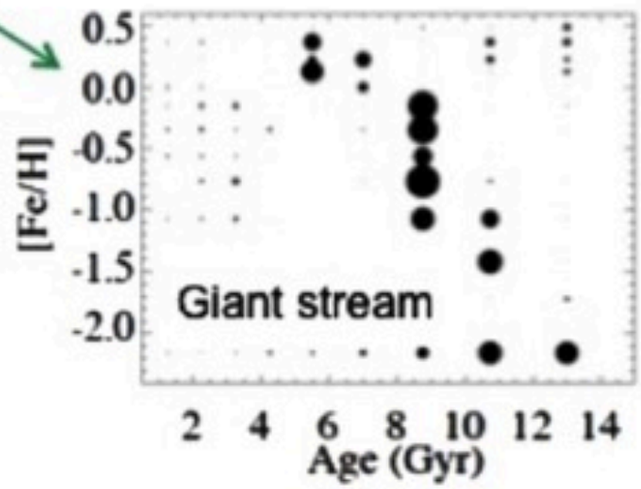












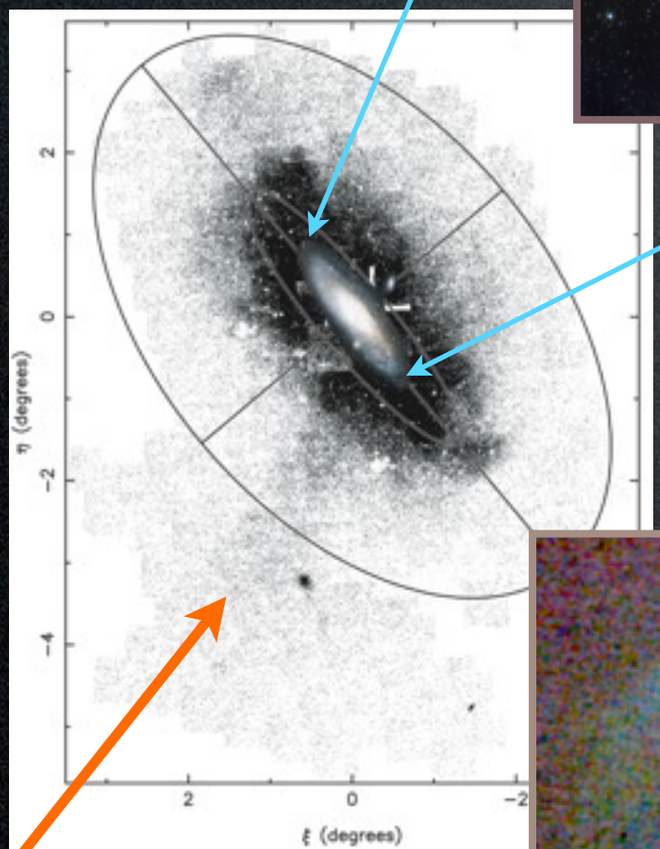
disk, stellar age < 5Gyr

Stellar ages by Brown et al. 06,07,08

>5-8Gyr

Andromeda galaxy (M31)

Classical bulge indicatif of major merger origin

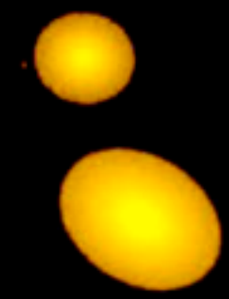


Giant Stream

Ibata+2005

PandAS McConachie+2009 with CFHT

-8M particles
-Color code for stellarage:



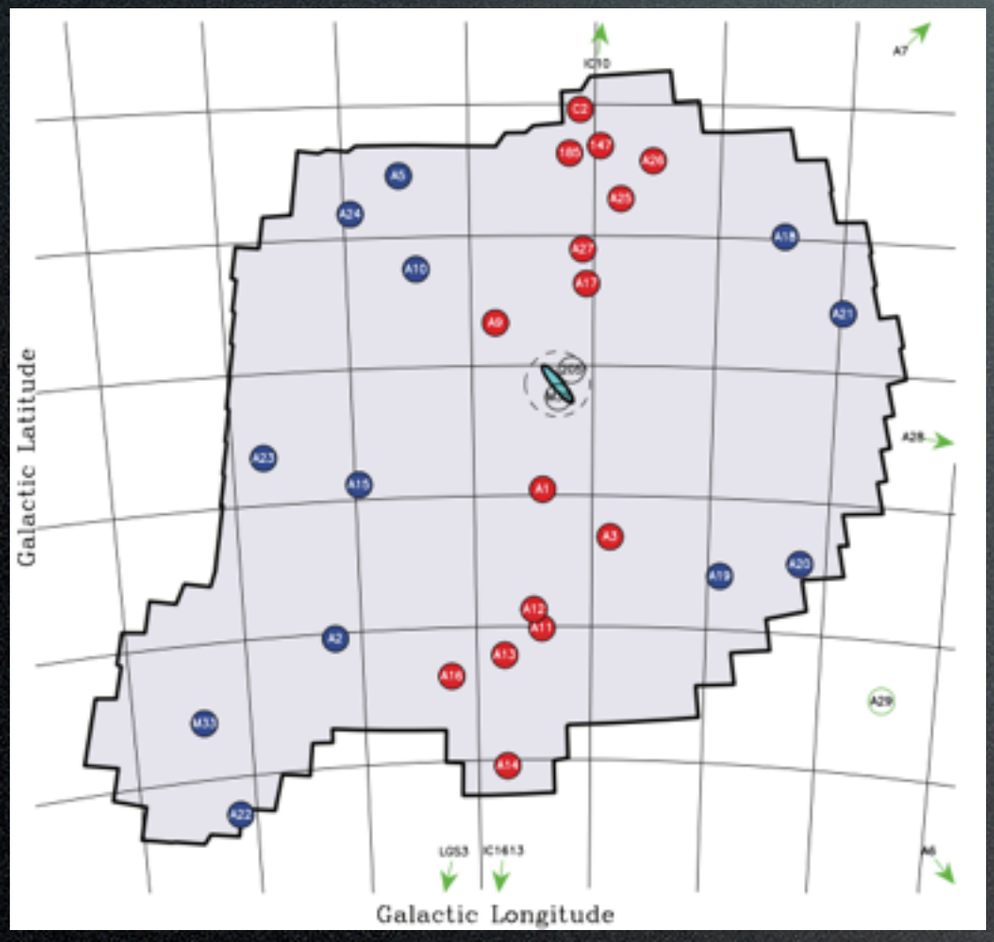
Hammer et al. 2010

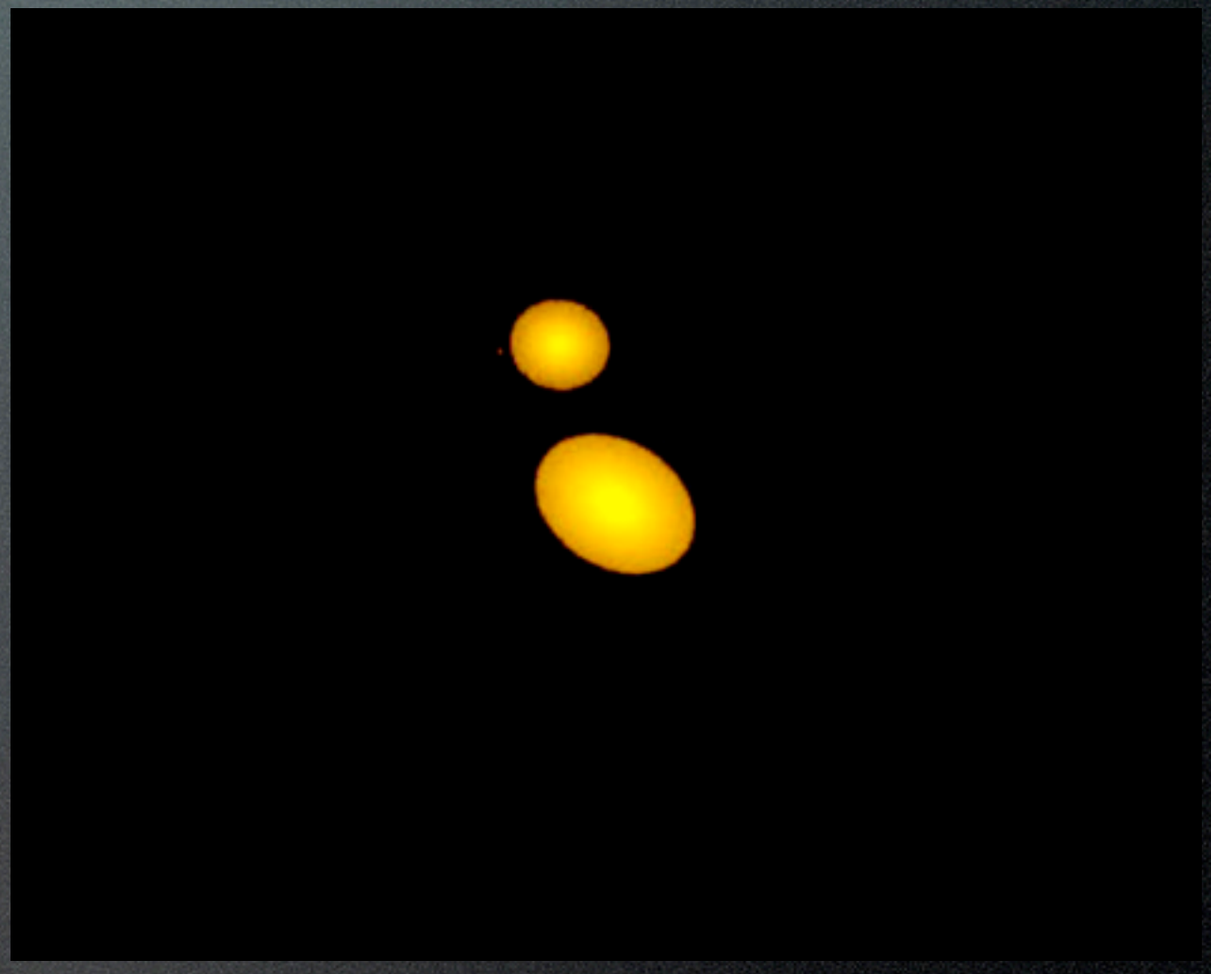
A 3:1 gas-rich merger model reproduces:

- ✓ Rotation curve
- ✓ Bulge-to-total mass ratio : B/T = 0.28
- ✓ Scale length of thin disk Rd = 5.6 kpc
- ✓ Thick disk (10% of total stellar mass)
- ✓ 10-kpc, HI star-forming ring
- ✓ Giant stream both position and kinematics
- ✓ Age distribution of stars

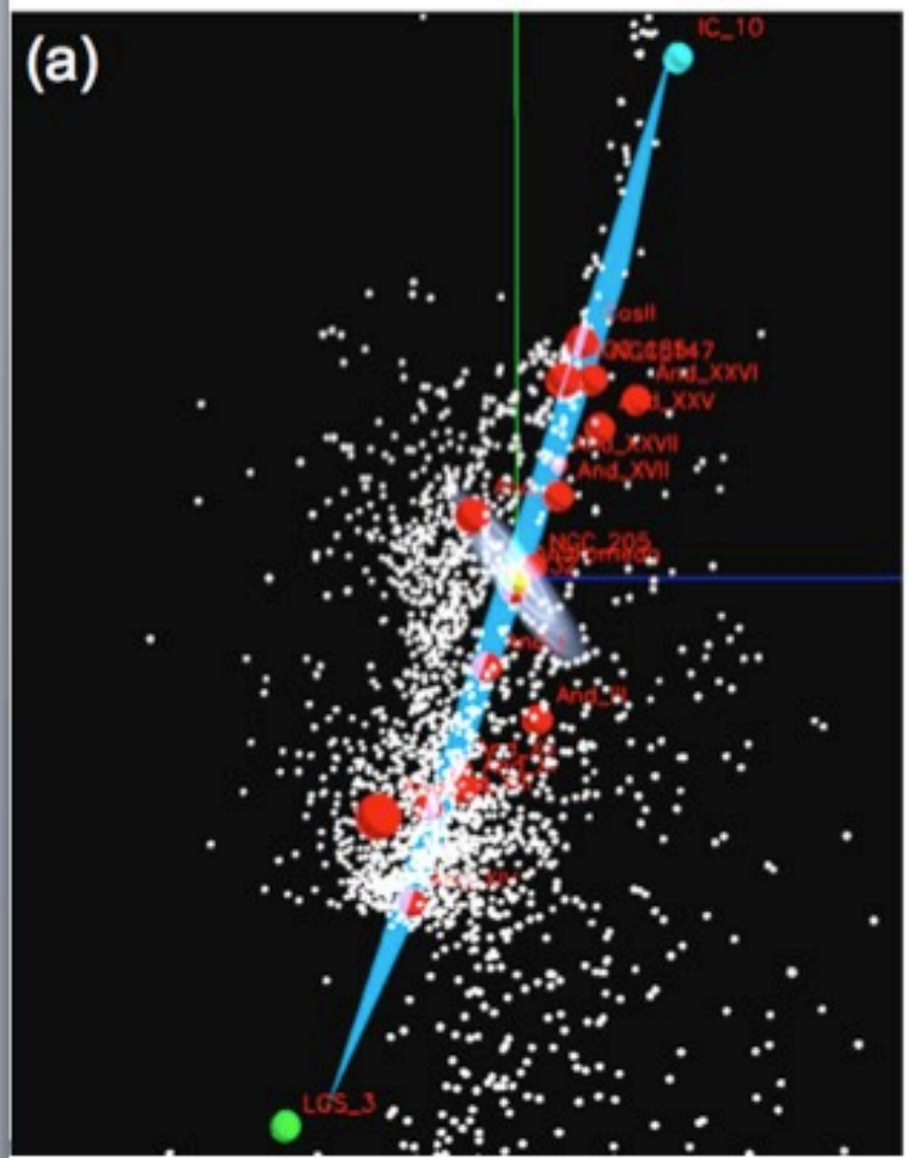
«A Vast Thin Plane of Co-rotating Dwarf Galaxies»
(Ibata **2013** Nature)

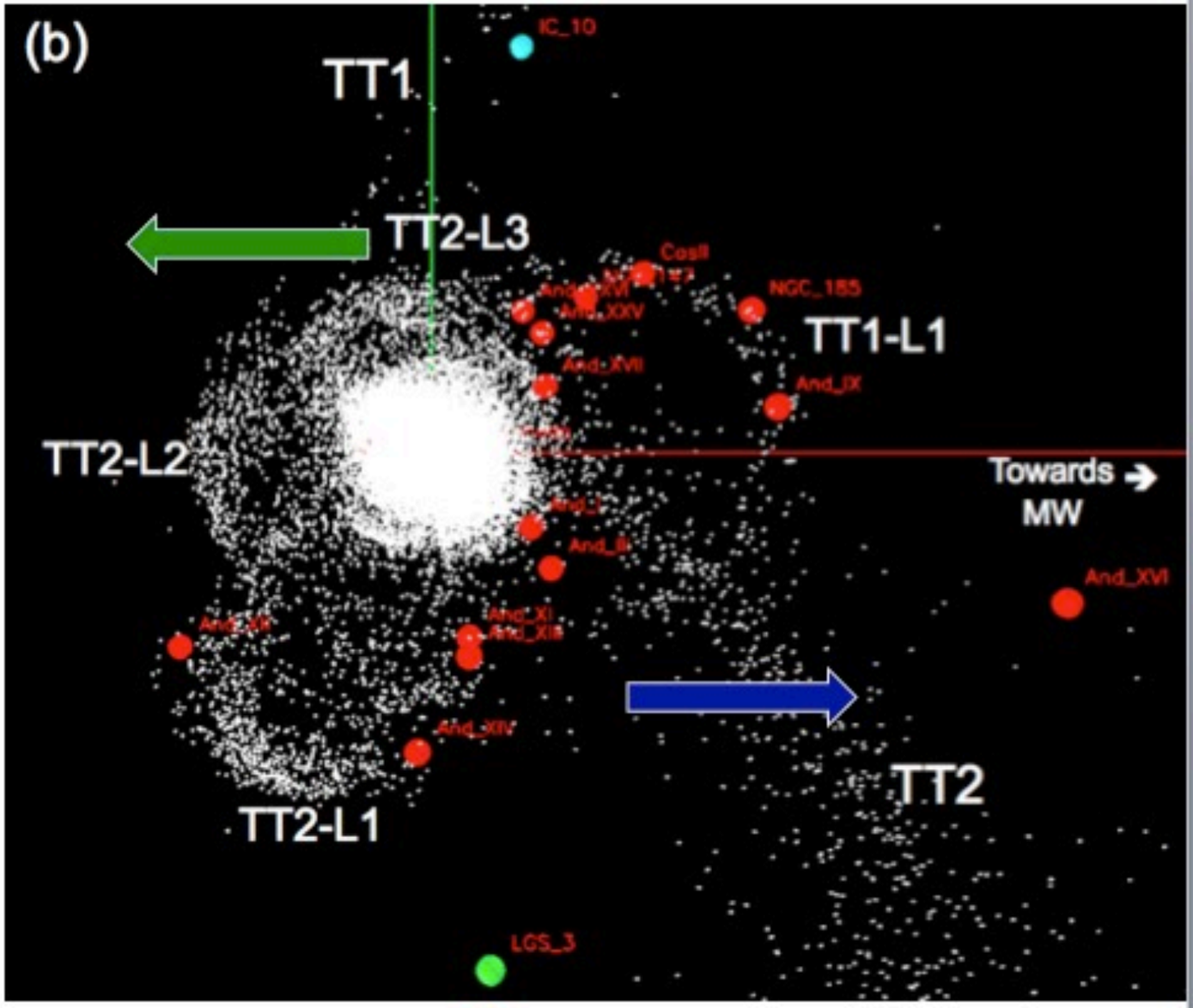
-15 satellite galaxies are located in a plane (up to 400kpc) center at M31 and coherent in radial velocities
- The plane includes our MW in 1 degree.



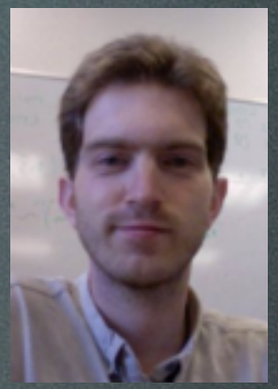


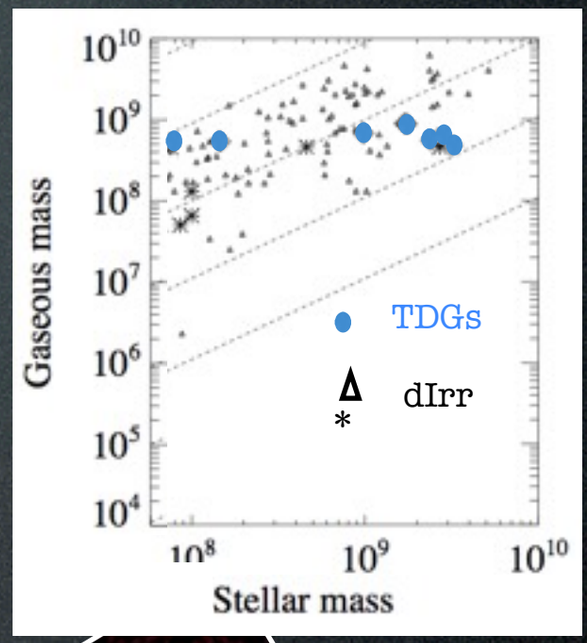
Hammer et al., 2013, MNRAS, 431, 3343



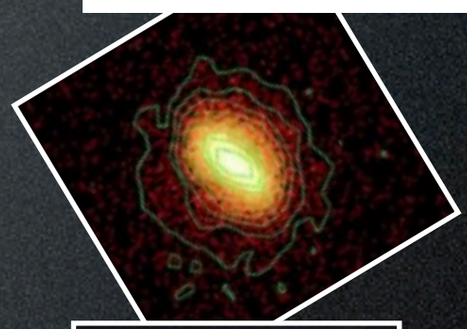


S. Fouquet+2015 (submitted)

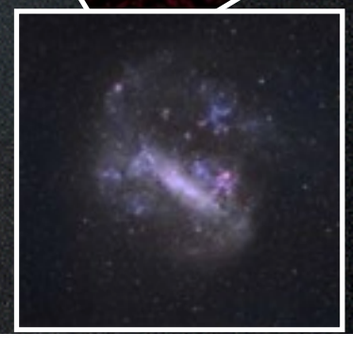




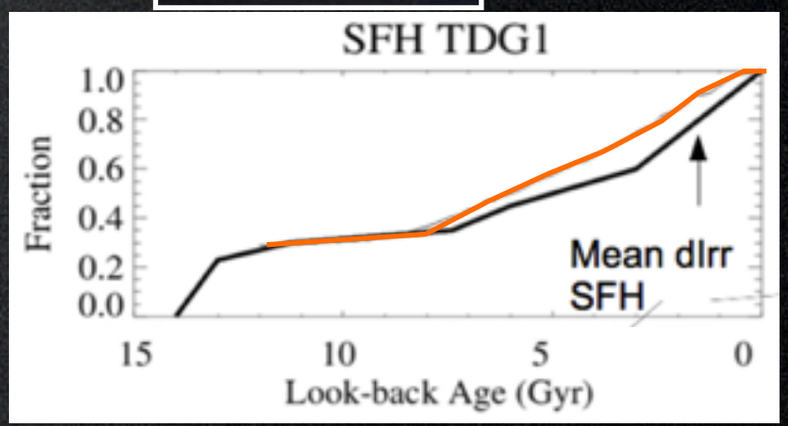
TDGs, gas-rich



simulated TDG



LMC



Future work
-- Gizmo (Hopkins 2014)
-- Ploeckinger et al. (2014, MNRAS)
... ...

The Local Group

The Sun

$(l,b)=(121^\circ, -21.5^\circ)$

IC10

780 kpc

M32
M33
And 1,2
... ...

dTrans
....

dwarf spheroidals (classical)

Leo I
LeoII
Fornax
Darco
Sextans

Sculptor
Carina
UMi
Sagittraius

ultra-faint dwarf spheroidals
(SDSS and DES)

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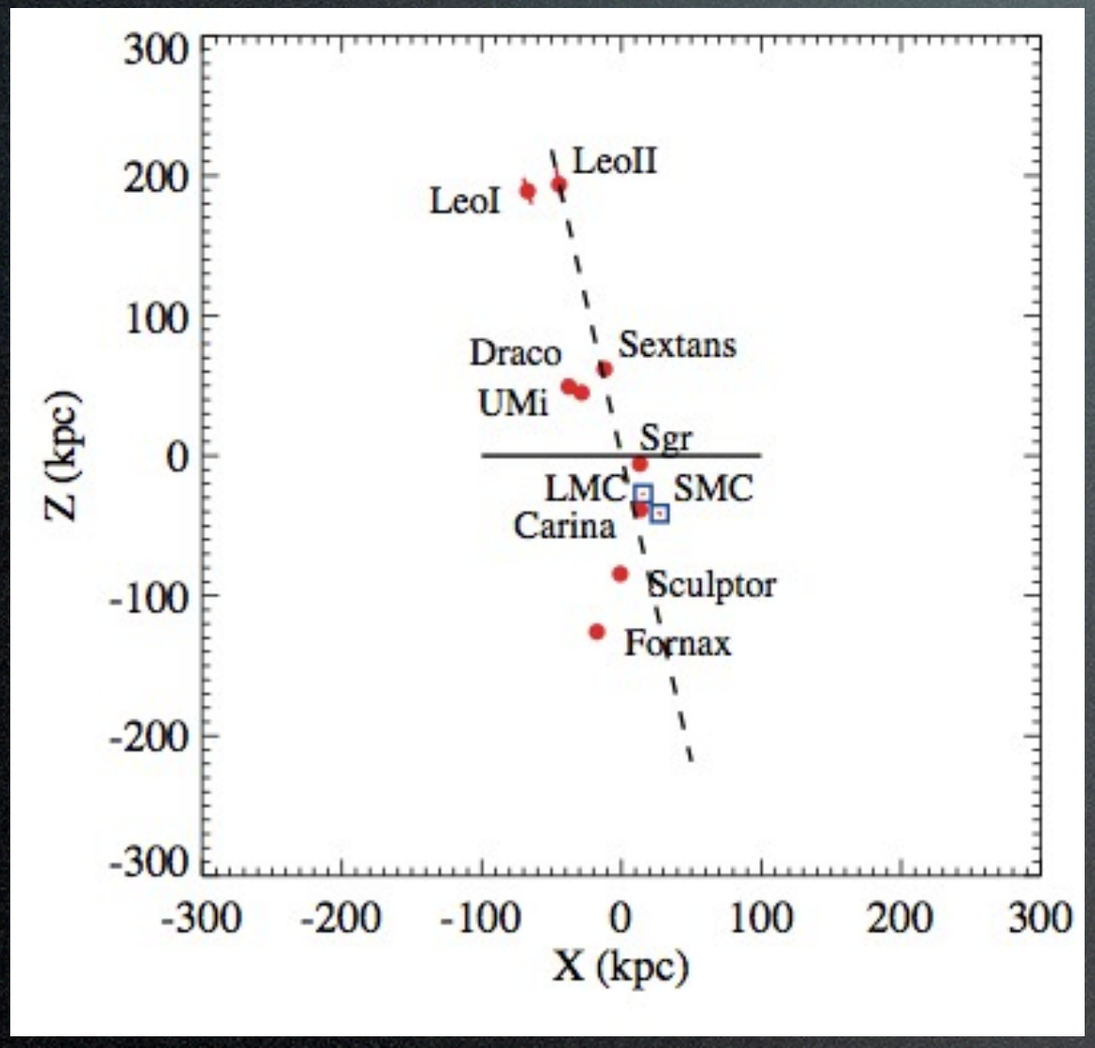
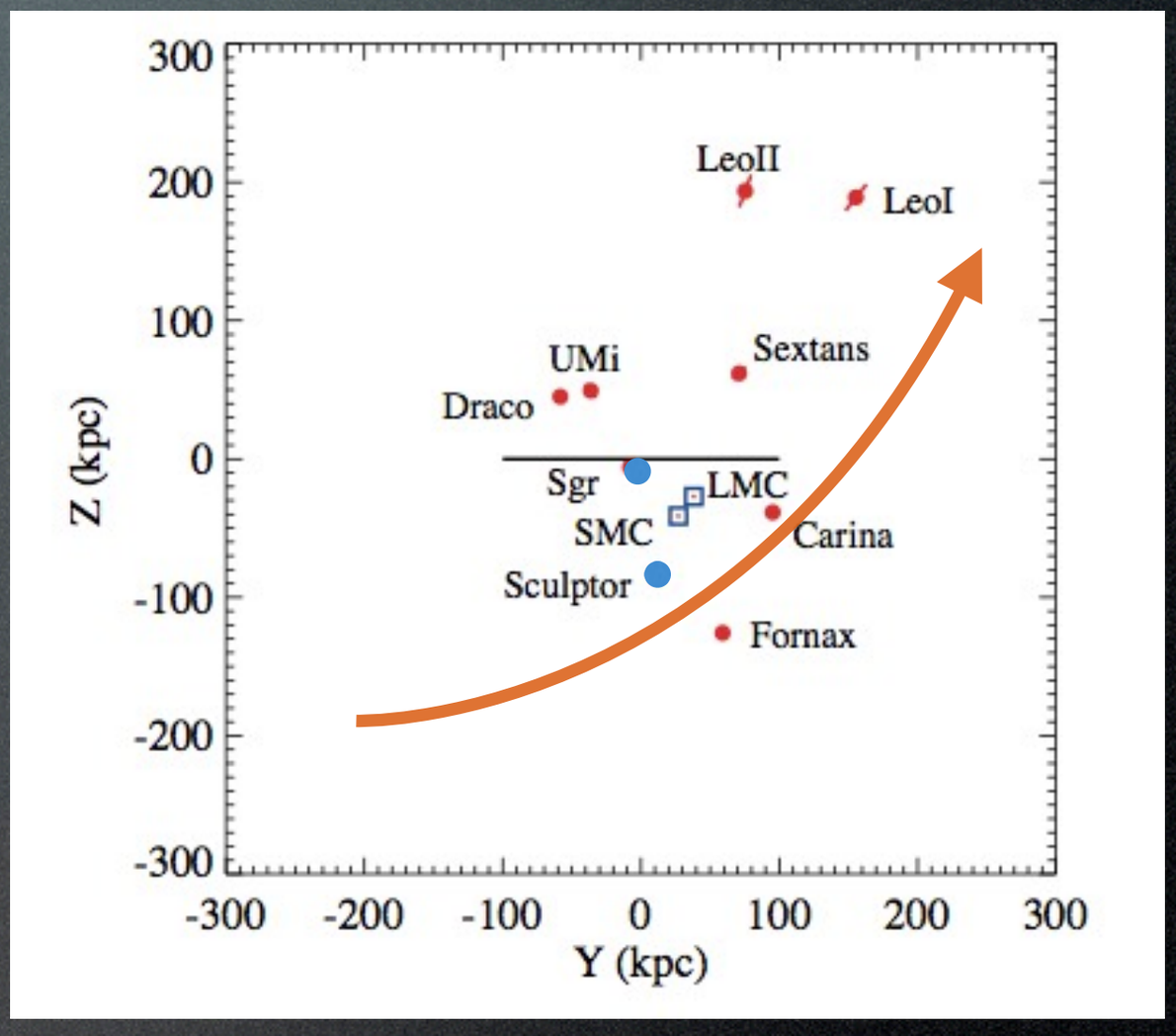
DoS: Disk of satellites (Kunkel & Demers 1976; Lynden-Bell 1976, Kroupa et al. 2005)

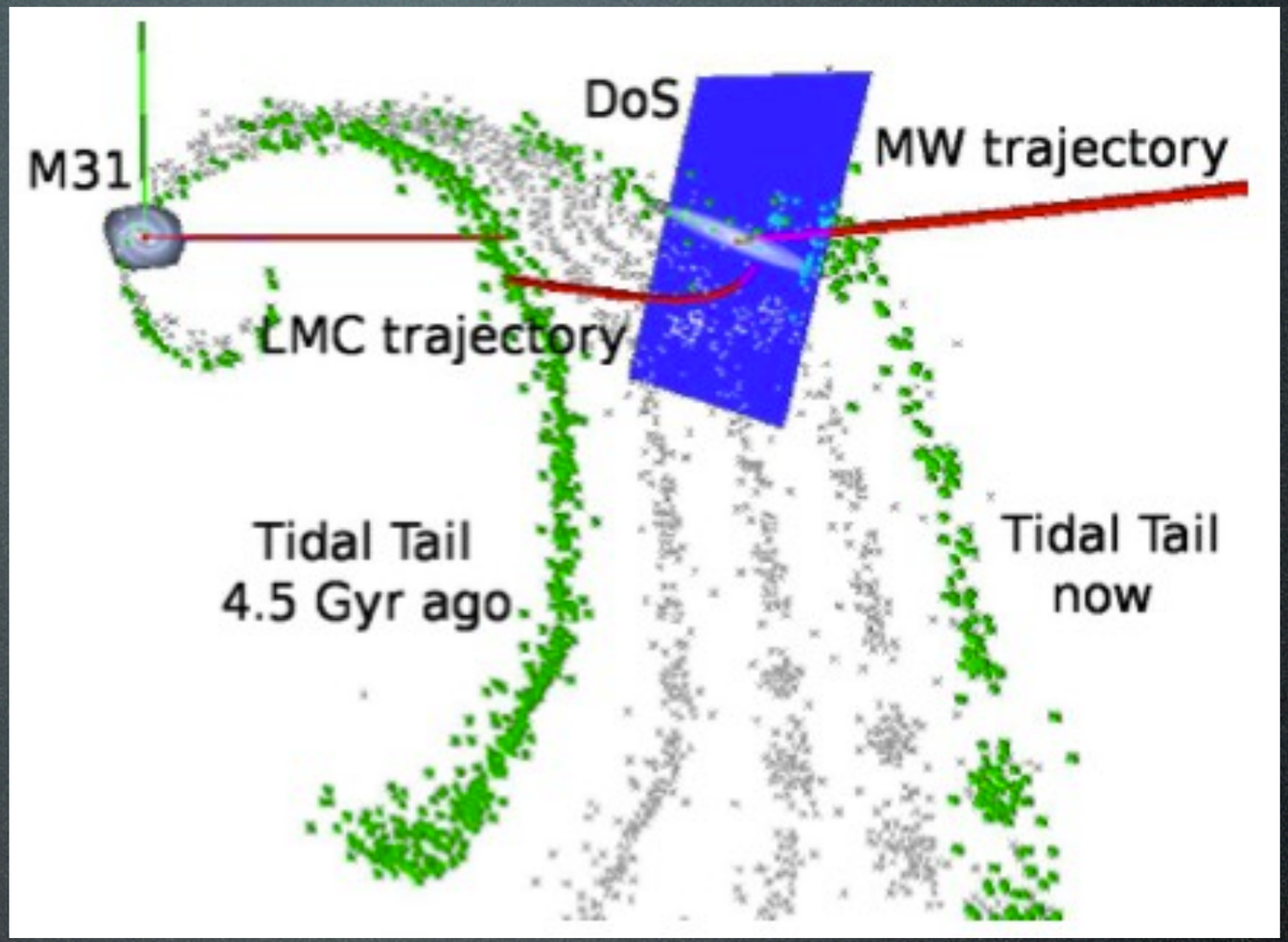
VPOS: a vast polar structure of satellite galaxies (Pawlowski 2012)

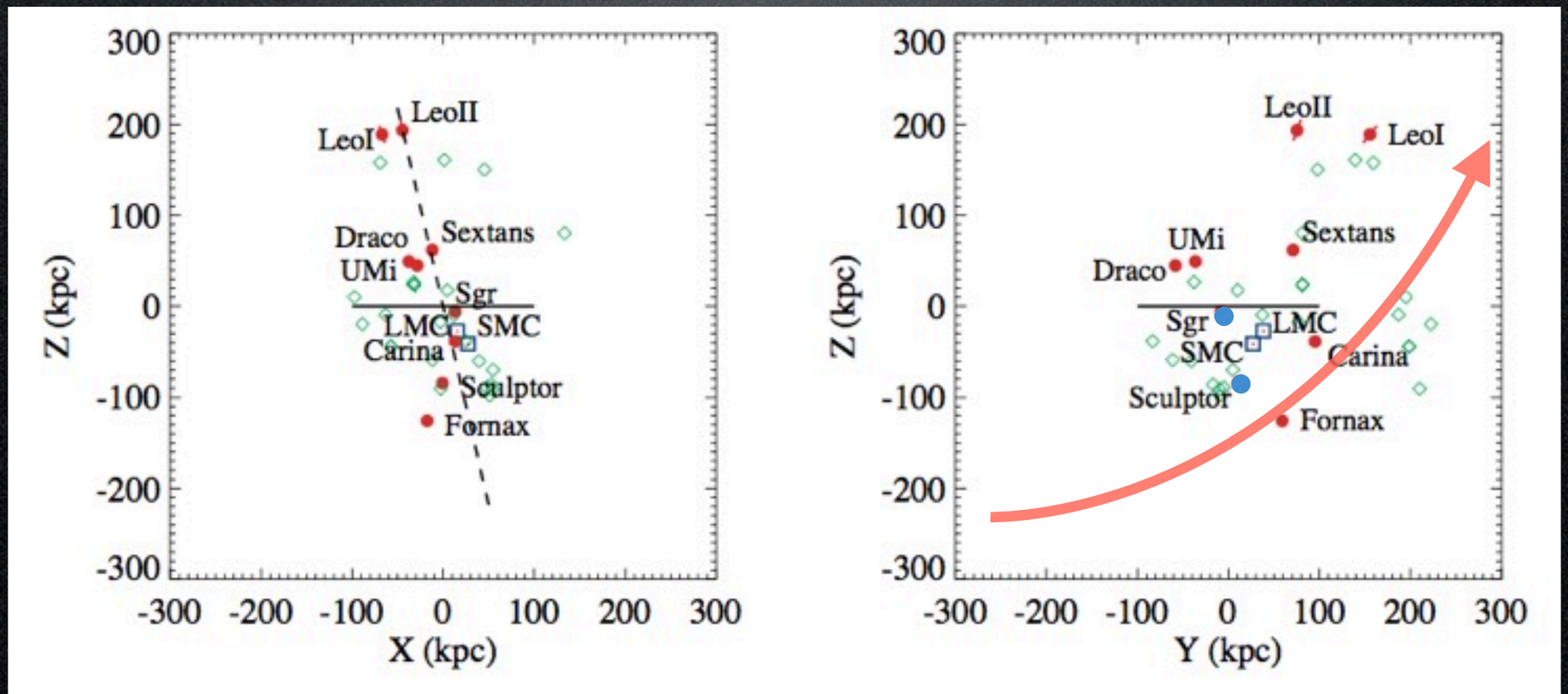




S. Fouquet+2012

S.Fouquet+2012





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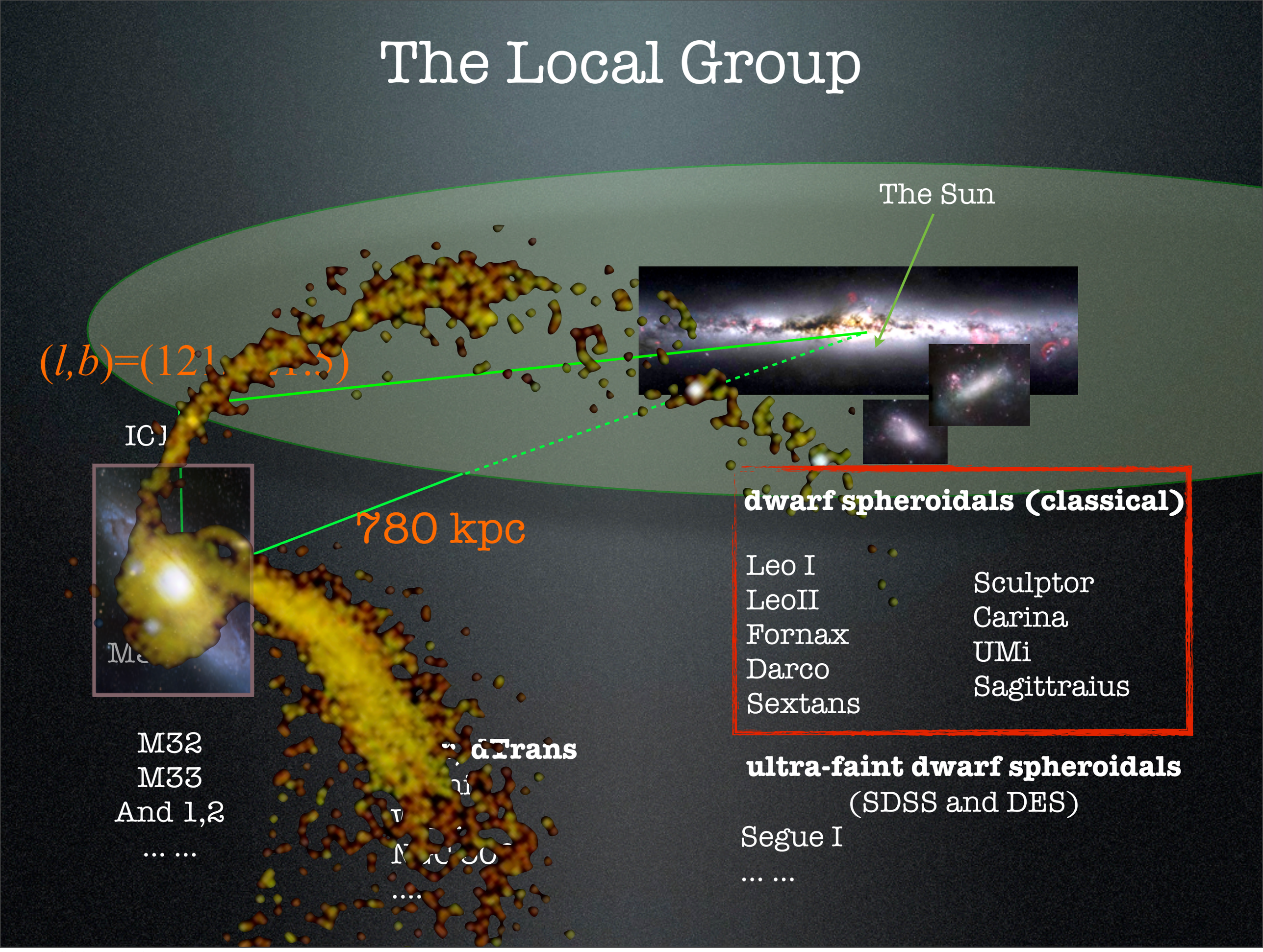
The Local Group



Leo I

Fornax

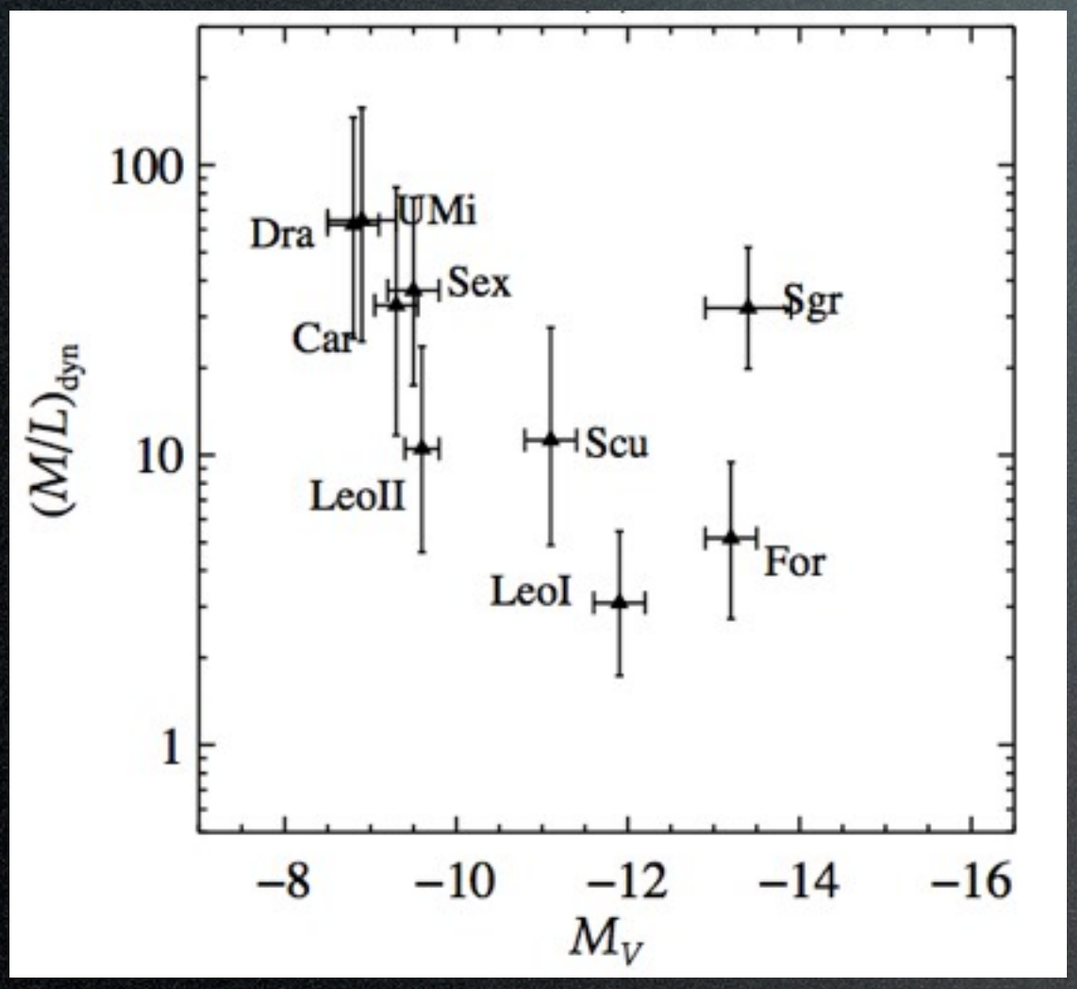
Sculptor

Draco

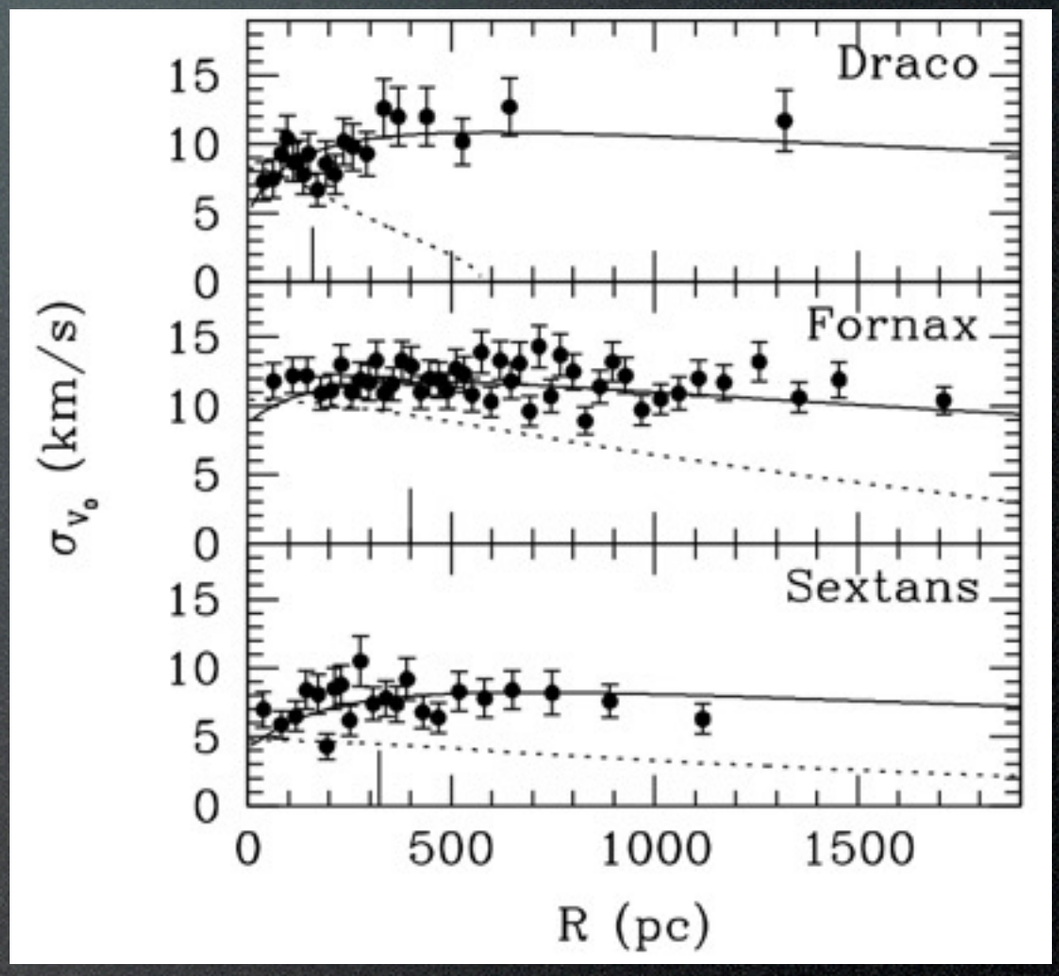
... (9 dSphs)

MW satellites: assumed to be Dark Matter dominated

- High dynamical (M/L)



- Flat velocity disperion profile



Walker+07,09,12

Gas-rich TDG & the MW interactions

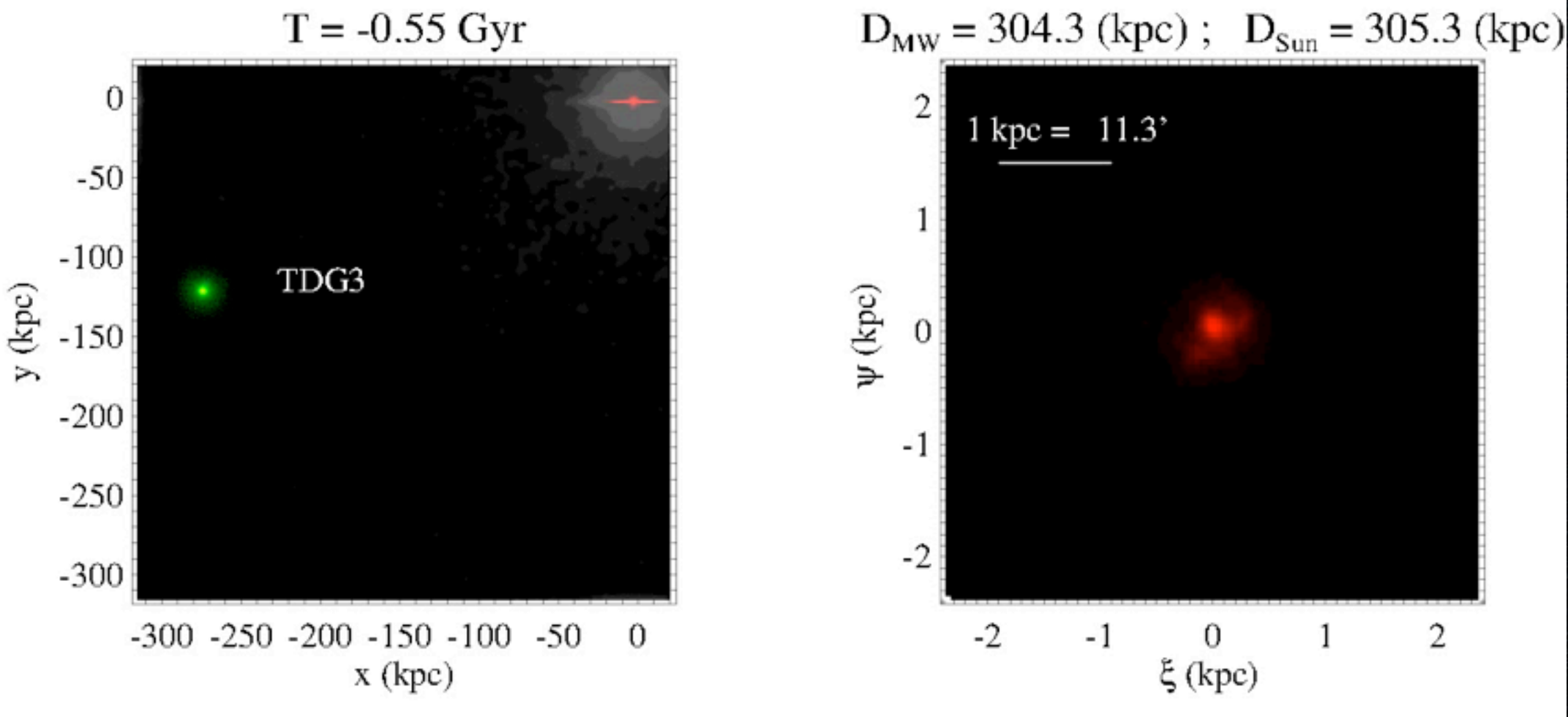
- N-body hydrodynamic simulations
- MW model (bulge+disk+ Gasous Halo +dark halo)
  (T>$10^{5\text{-}6}$ K, Mayer 2009)
- TDGs taken from M31 simulations (Hammer+10)
  - TDGs are free of DM and gas-rich > 90% in term of mass
- hyperbolic orbits <-- M31 motion+Tidal Tail motion

From gas-rich TDG to dSph

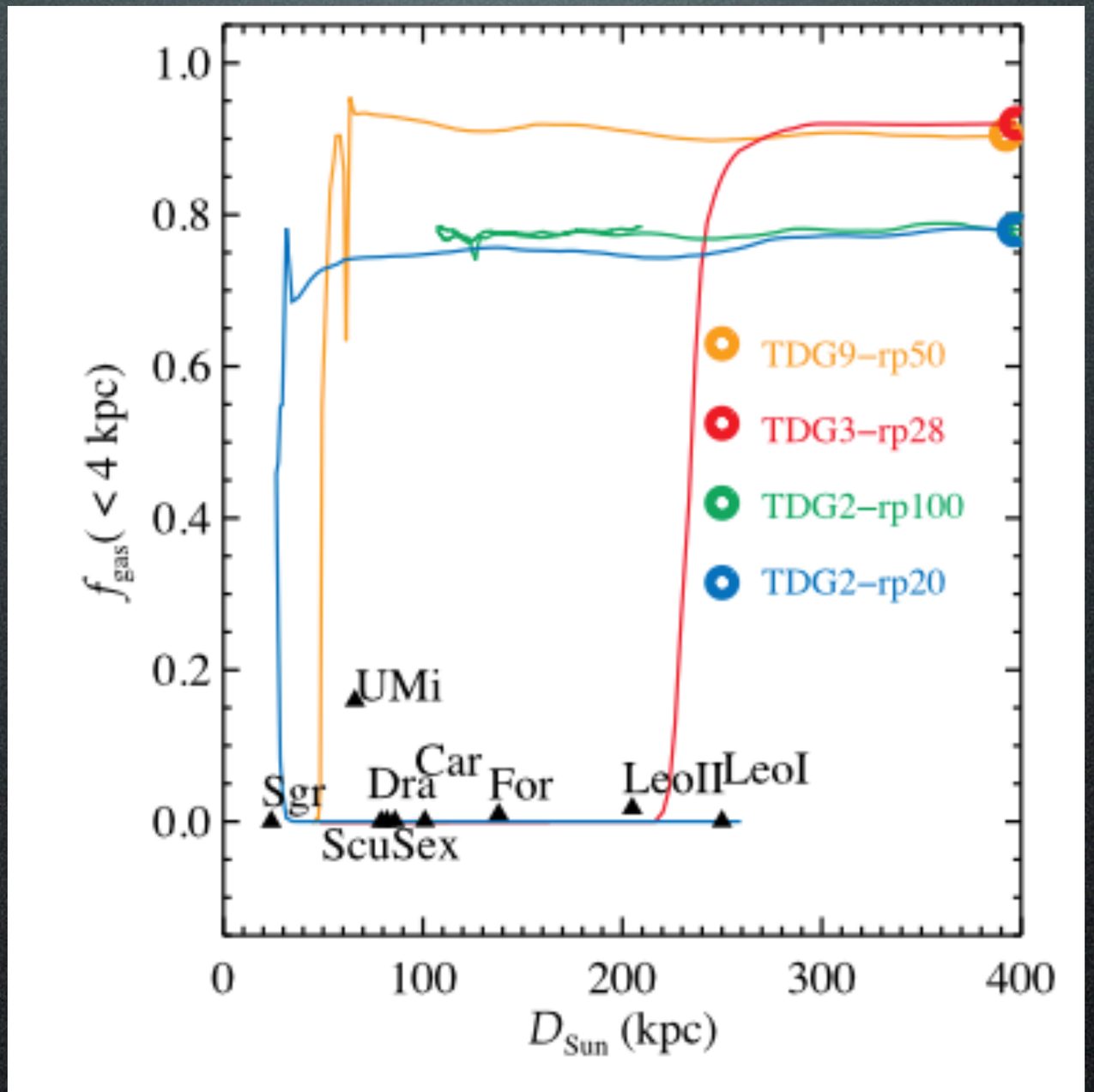
TDG3:
m_{star} = 1 x 10^7 Msun
m_{gas} = 1 x 10^8 Msun

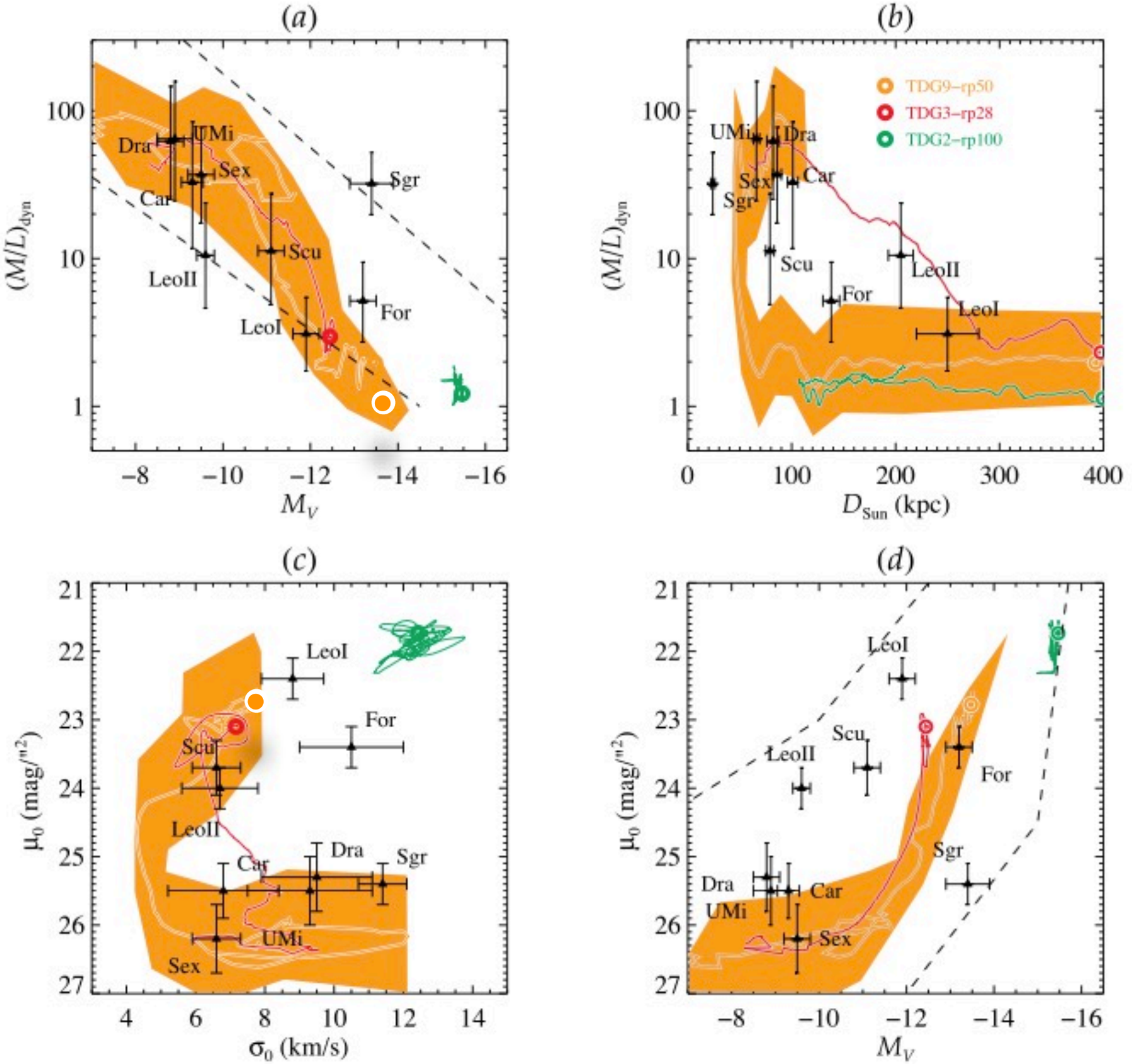
View from the Sun

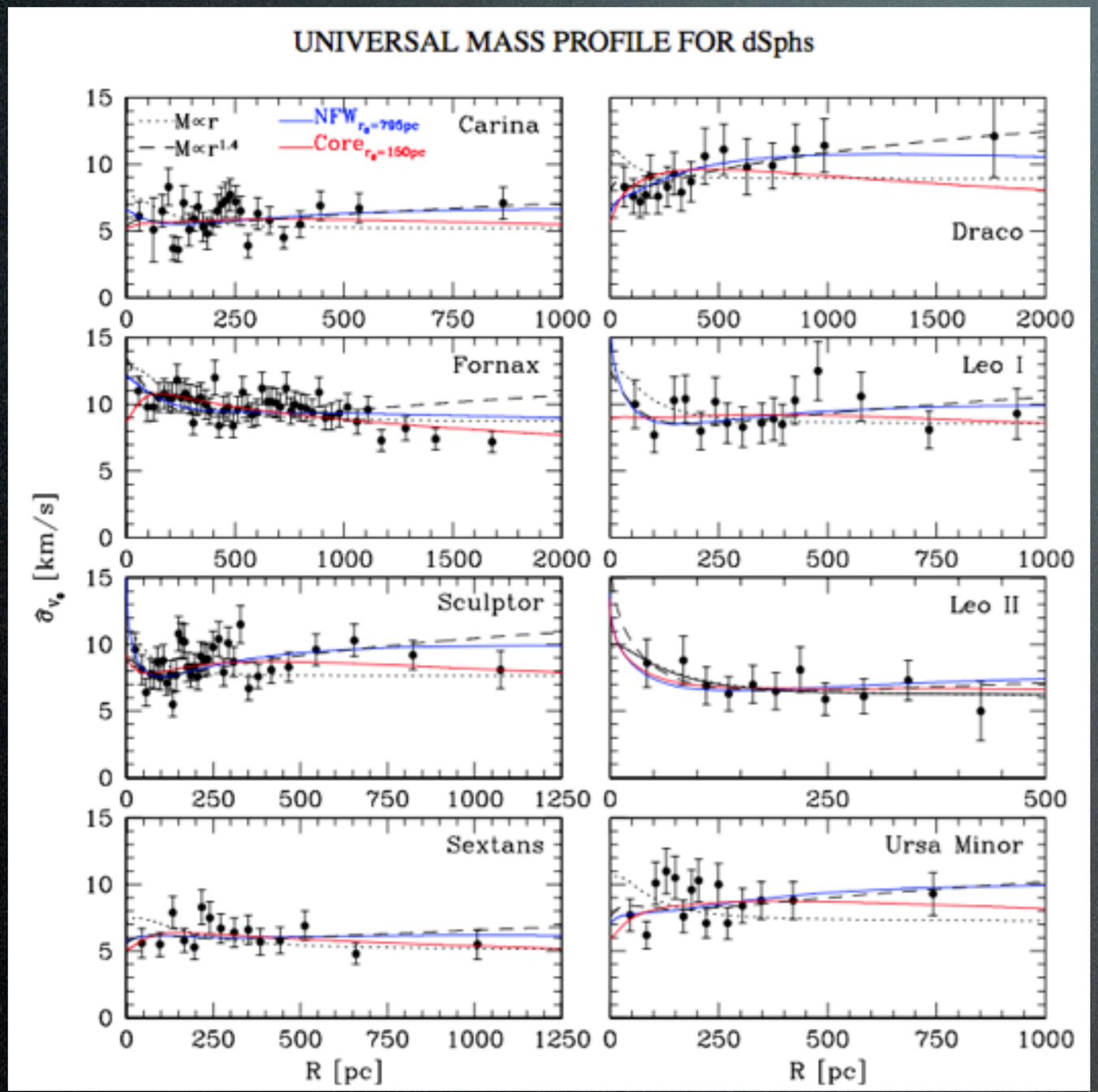
Limit Obs. 28 mag/arcsec^2

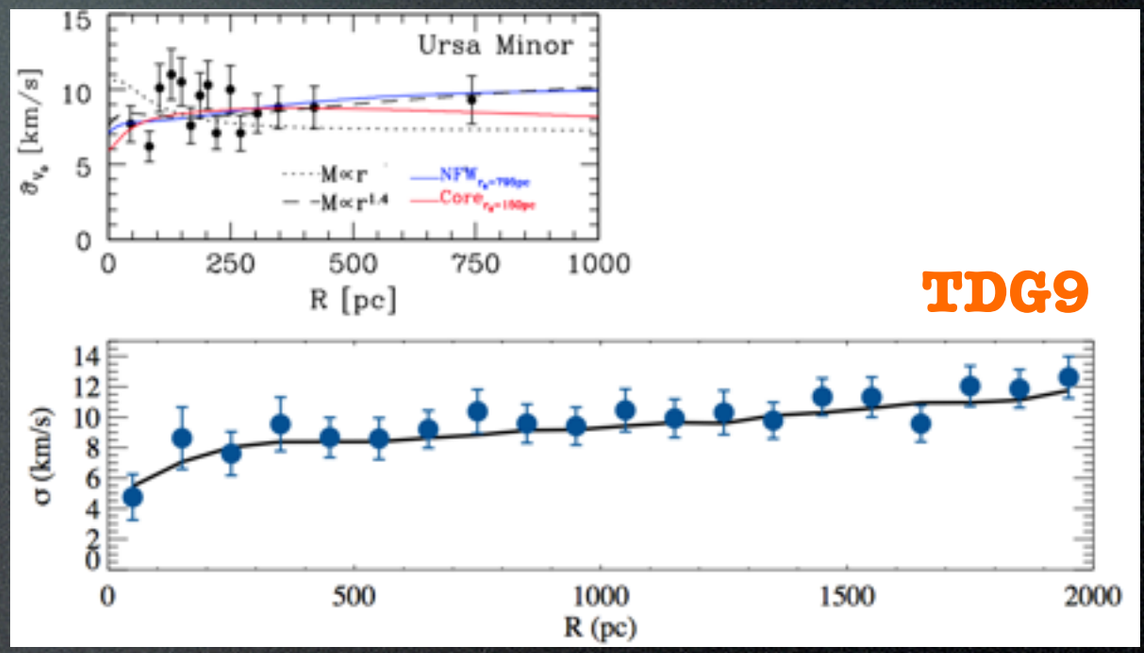


about 1 M star particles for TDG in order to follow the expansion of stars


1.0
0.8
0.6
0.4
0.2
0.0
f_{gas}(< 4 kpc)
TDG9−rp50
TDG3−rp28
TDG2−rp100
TDG2−rp20
UMi
Car
Sgr
Dra
For
LeoII
LeoI
ScuSex
0
100
200
300
400
D_{Sun} (kpc)


(a)
(b)
(c)
(d)
$(M/L)_{dyn}$
M_V
D_{Sun} (kpc)
μ_0 (mag/"^{2})
σ_0 (km/s)
TDG9−rp50
TDG3−rp28
TDG2−rp100
Dra
UMi
Sex
Car
Sgr
Scu
LeoII
LeoI
For





TDG9

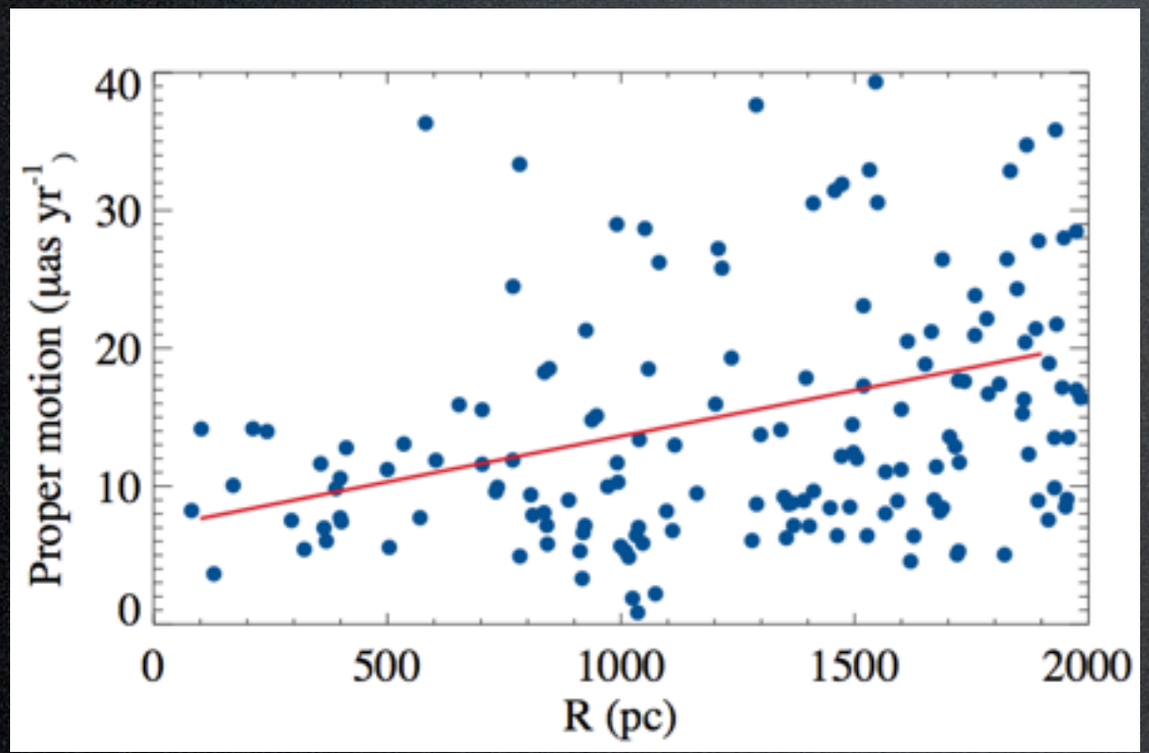
Walker+2009

Conclusion

- **MW dSphs could be the residues of tidal dwarf galaxies (Kroupa,1997).**
  1. When gas-rich TDGs interact with MW hot gaseous halo, they may completely loss their gas.
  2. Then, as a consequence, their stellar content is progressively driven out of equilibrium and strongly expands, leading to low surface brightness feature and mimicking high dynamical M/L ratios.

- **The problem of missing satellites is severely strengthened by our results not only because of TDG but the TDGs originated from M31.**

- **A prediction of the Expansion of dSph**

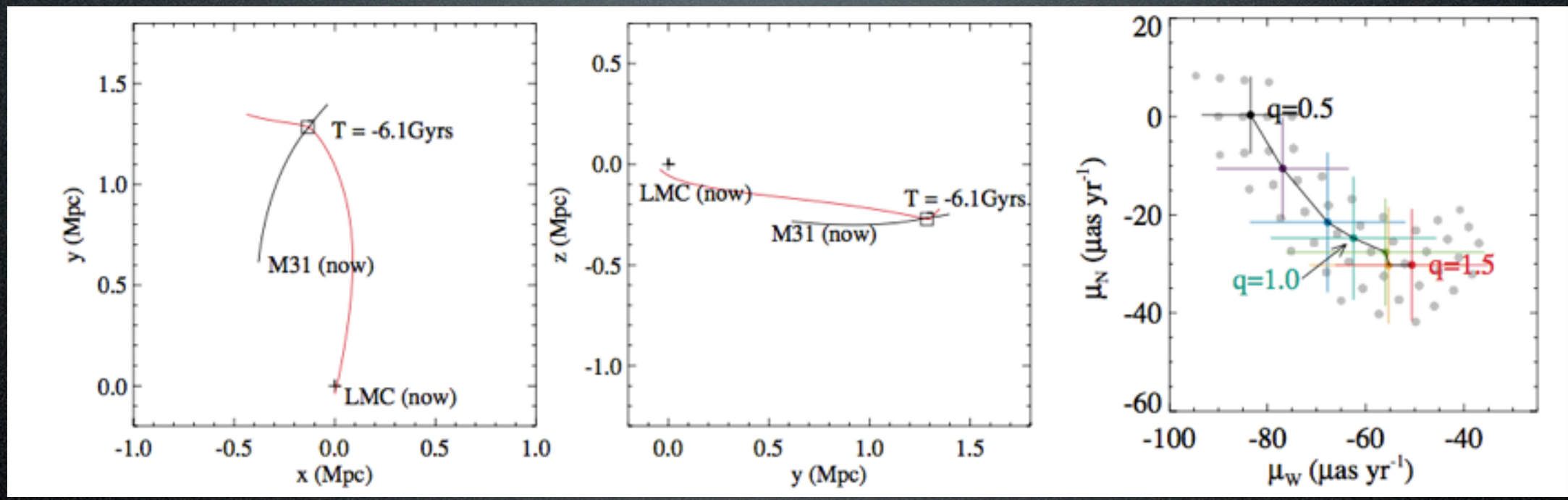


Yang et al. 2014, MNRAS

Merci.

Appendix

Yang & Hammer 2010



$$\mu_W = -62 \pm 18\ \mu\text{as yr}^{-1},$$

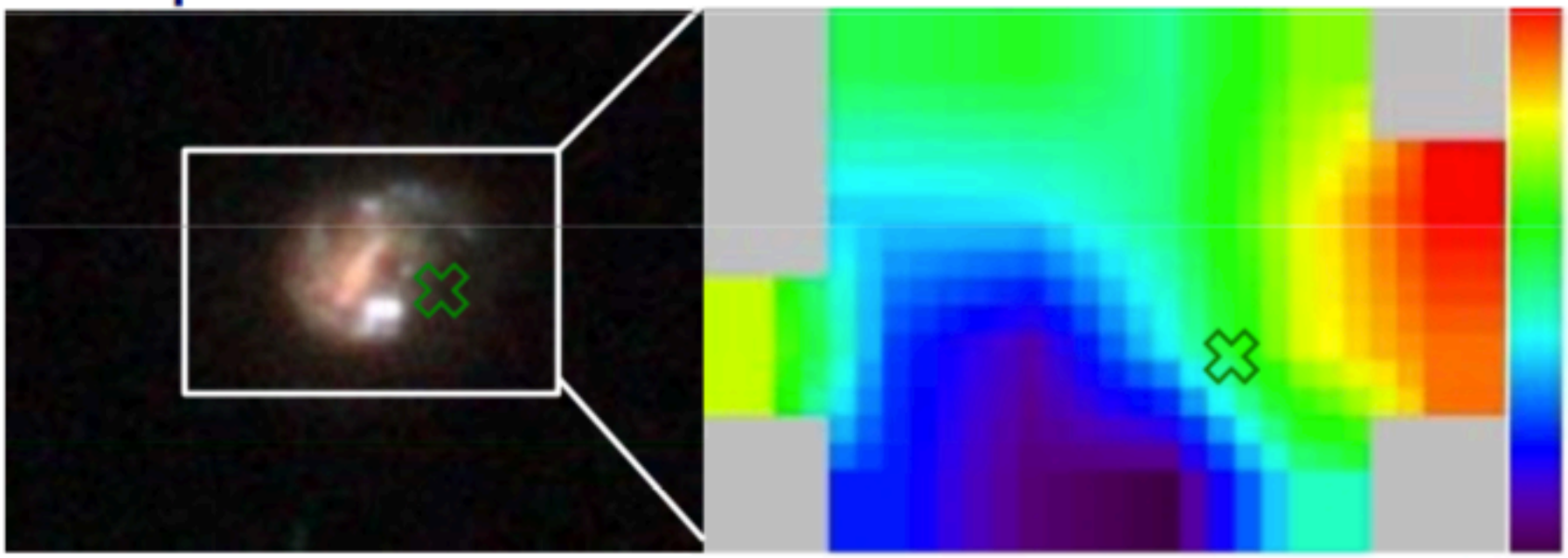
$$\mu_N = -25 \pm 13\ \mu\text{as yr}^{-1},$$

q=1.0

Associating Morpho-kinematics with physical processes

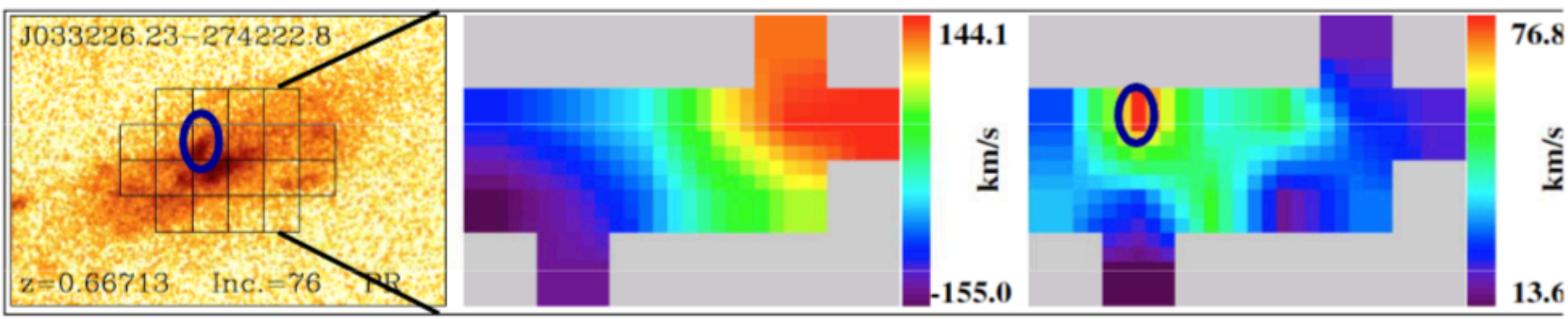
Associating Morpho-kinematics with physical processes

Complex kinematics: kinematic disturbances are global not local



GIRAFFE IFU resolution ~ 7 kpc @ z=0.6

HST-ACS | Velocity field | σ map



Minor merger (15:1): only tiny effect on σ map

Puech et al. (2007)

Associating Morpho-kinematics with physical processes

Outflows:

- only a handful of galaxies have significant shifts between abs. and emission lines (Hammer et al. 2009; Rodrigues et al., 2012).

Clump fragmentation & cold flows:

- only 20% of anomalous galaxies are clumpy (Puech, 2010)
- cold gas accretion tends to vanish in massive halos at z<1 (<1.5 Mo/yr at z~0.6 see Keres et al. 2009, Brooks et al. 2009)

Secular evolution:

Kinematic perturbations are too strong and extended