Stellar populations in the Local Group dSphs : when the numerical simulations meet the observations

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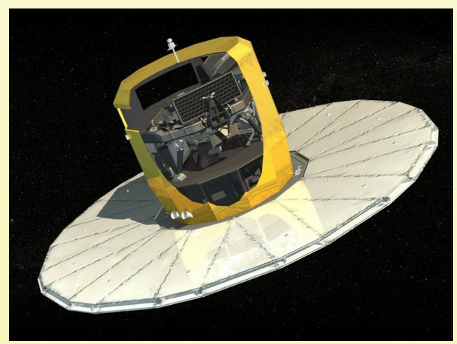

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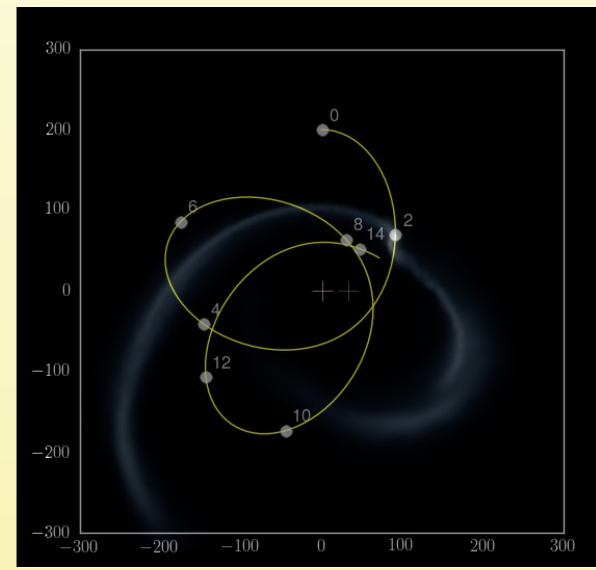

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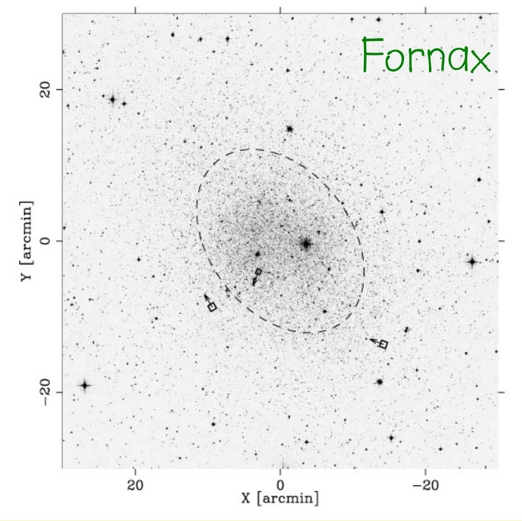
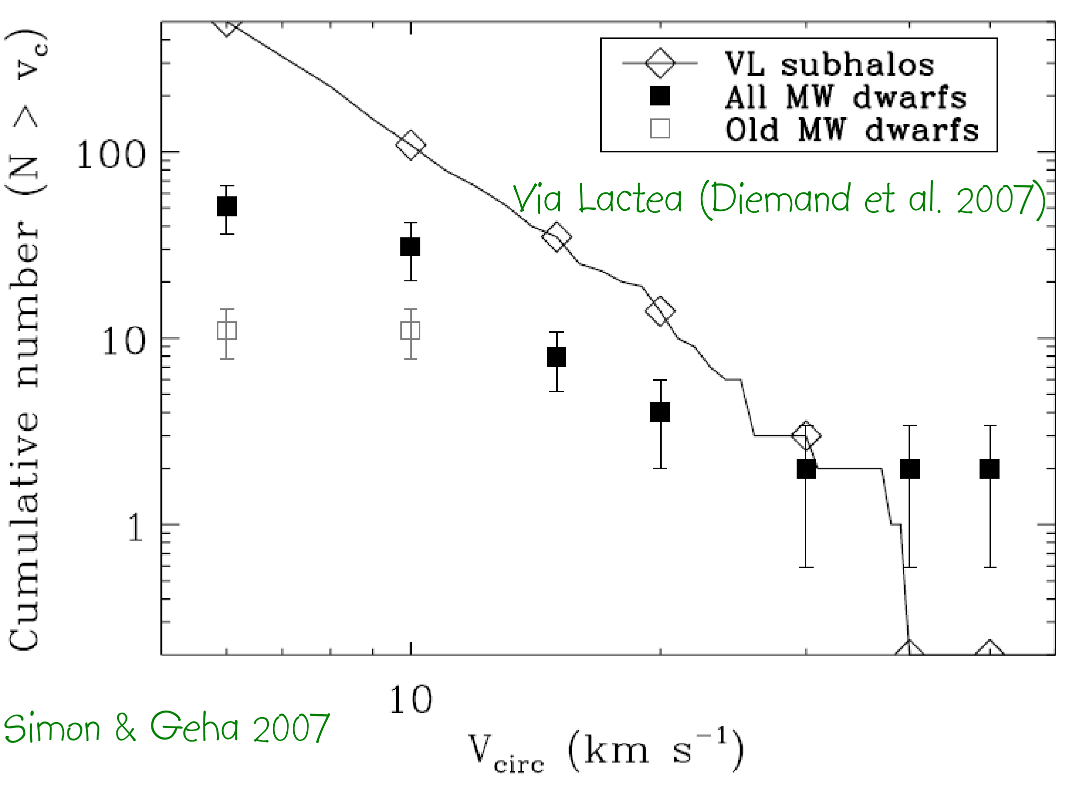
The interest of dSphs ?

- Dwarf galaxies are the faintest objects (Lv down to 300 Lsun), at the low end of the luminosity function

➔ Represent an excellent test for the LCDM paradigm

- LCDM predics :
  - Ubiquitous around MW-like galaxies (missing satellite problem, Kauffmann et al. 93)
  - Strongly dark matter dominated
  - Building blocks of larger structures



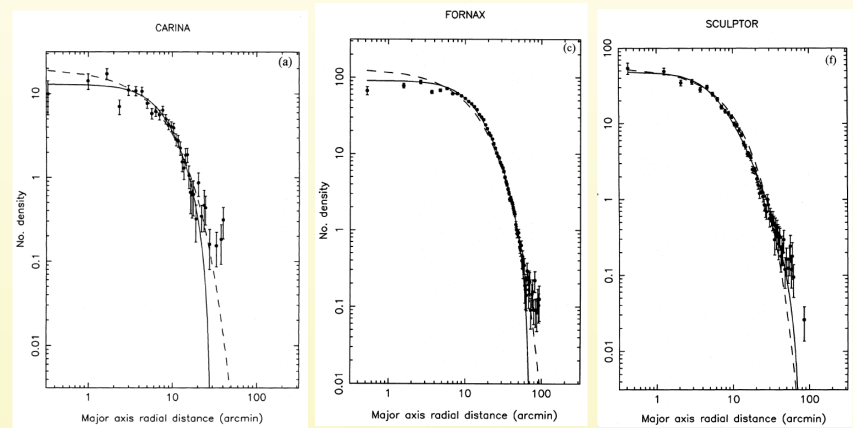


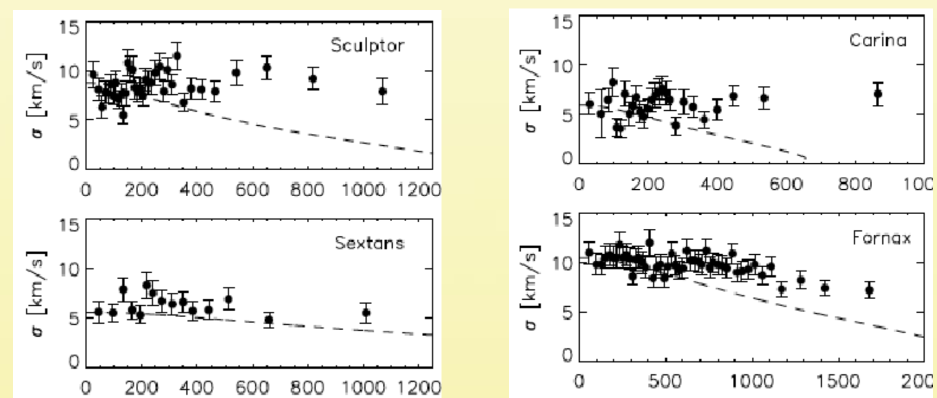
Simon & Geha 2007

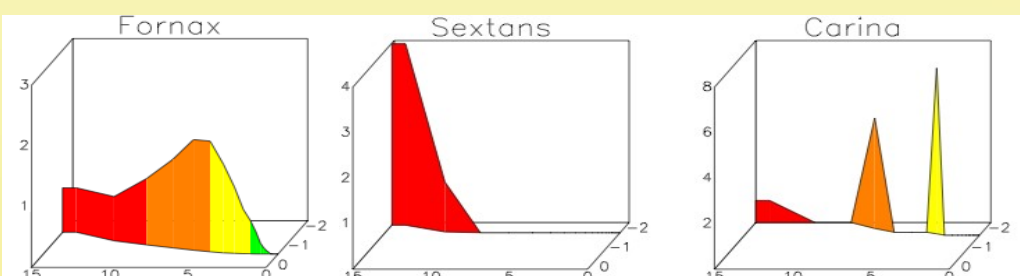
Accurate measurements

Thanks to their proximity (~100 kpc), we have accurate measurements of numerous physical quantities

- luminosities (ex. Mateo 98, Walker et al. 09)
- stellar profiles (ex. Irwin & Hatzidimitriou 95)
- velocity dispertions (ex. Walker et al. 09)
- stellar ages (ex. Dolphin 05, de Boer et al. 11)







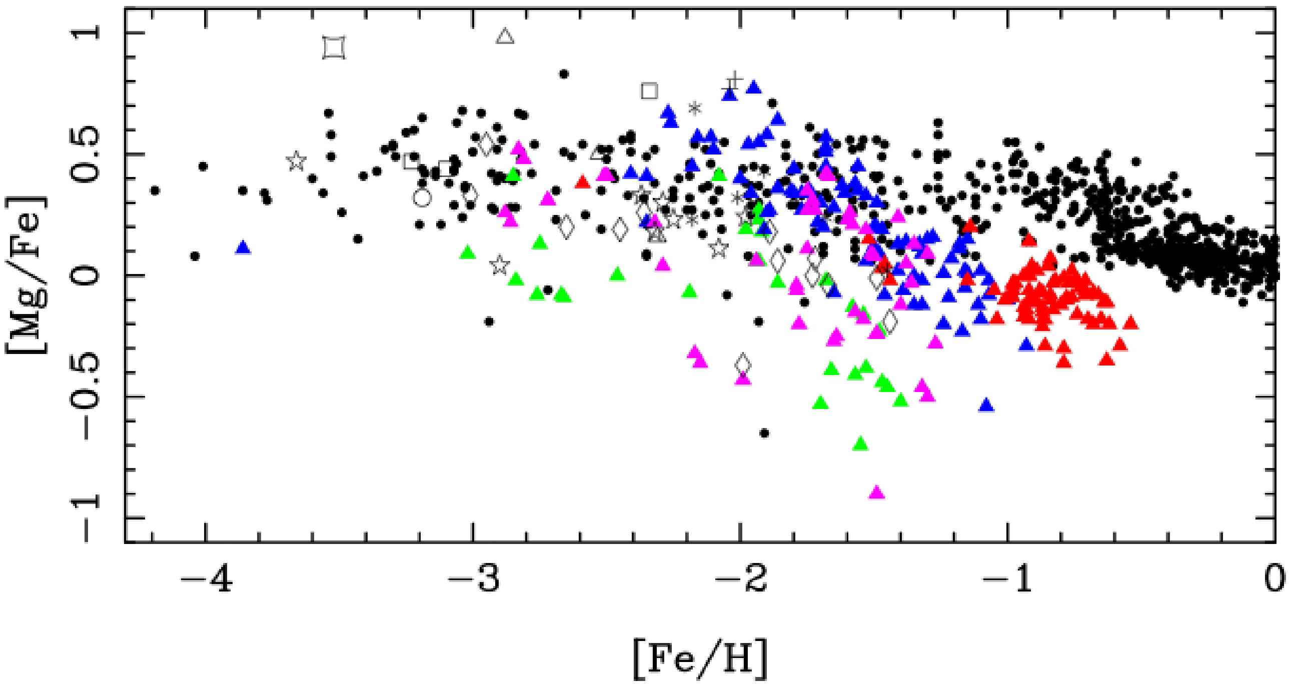
(Dolphin 05)

Accurate measurements

But also : very accurate measurements of chemical properties of <u>individual stars</u>

- metallicities + abundances (Fornax, Sculptor, Sextans, Carina)

(Shetrone et al. 2001, Koch et al. 2008, Aoki et al. 2009, Letarte et al. 2010, Venn et al. 2012, Hill et al. in prep., Lesmale et al. 2011, Jablonka et al., in prep.,)



Self-consistent modelisation of dSphs

Intrinsic or extrinsic evolution ?

The Code : GEAR, fully parallel Tree/SPH (Revaz & Jablonka 2012)

Skeleton :

- Gadget-2 (Springel 05)
  - gravity = treecode (Barnes & Hut 86)
  - hydro = SPH (Lucy 77, Gingold 77)

New inserted baryonic physics :

(see also Revaz et al. 2009)

Metal dependent cooling function

- above 10^4K (Sutherland & Dopita 93)
- below 10^4K, H_2, HD, OI, CII, SiII, FeII (Maio et al. 07)

Self-consistent chemical evolution :

- star formation (Katz et al. 92)
- single Stellar Population Scheme (SSP) (Poirier 03, PhD thesis)
- SNIa (Tsujimoto et al. 95,Kobayashi et al. 2000)
- SNII (Iwamoto et al. 99) nucleosynthesis
- feedback from SNs explosions thermal+blast (see Stinson et al. 08)

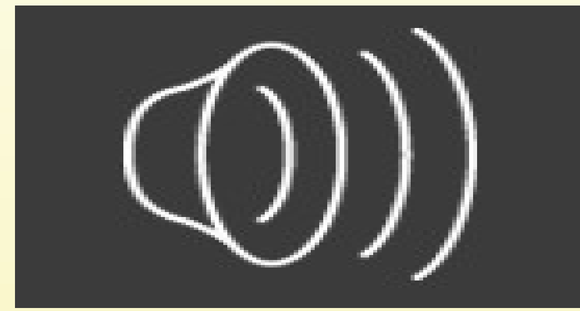
Initial conditions : isolated models

Isolated models :

- Pseudo-isothermal sphere (core)

  - halo and gas

  - in agreement with LCDM predictions



advantages :

- run a lot of simulations

- exploring a large range of parameters

C^*, e_{SN} but also N^*, rho^*, t_{ad}, IMF + total mass (10^8 - $10^9 M_{sol}$) , central density

>400 simulations

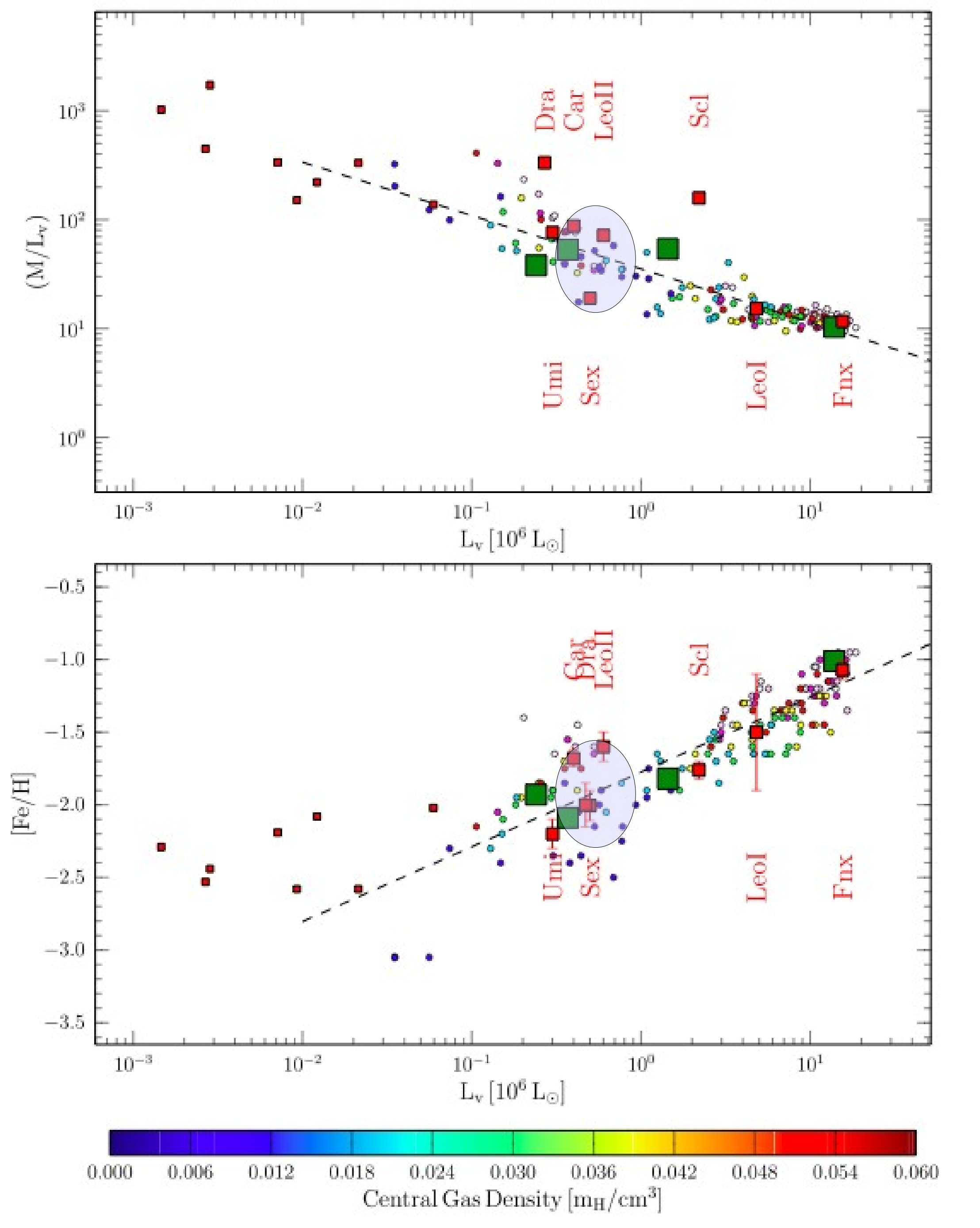
from 0 to 14 Gyrs

Reproducing global relations....

Objects with very similar :

- Lv
- [Fe/H]
- [M/Lv]

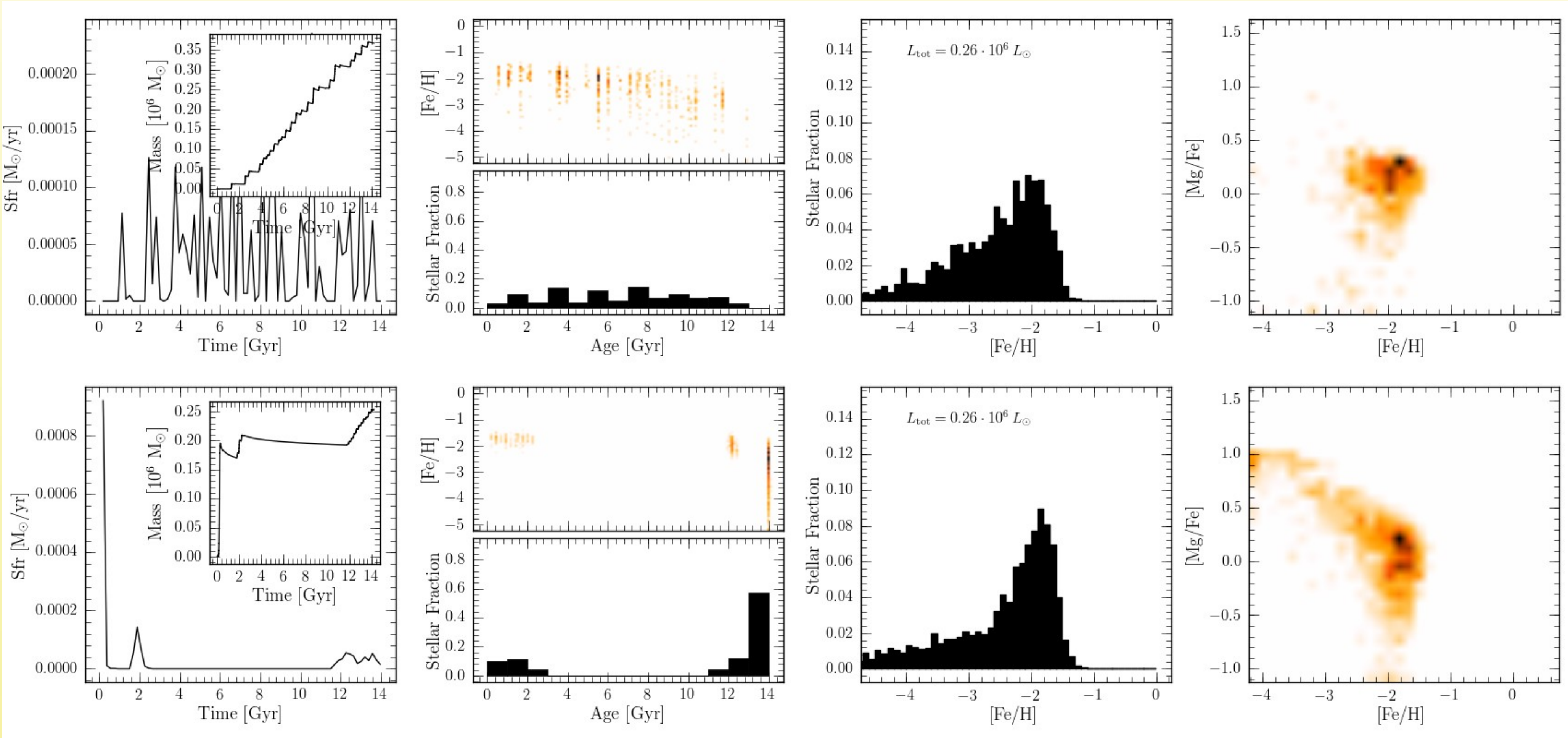
...



Revaz & Jablonka 2012

... may have completely different stellar and chemical properties !

SFR, M*   AGE   [Fe/H]   [Mg/Fe]

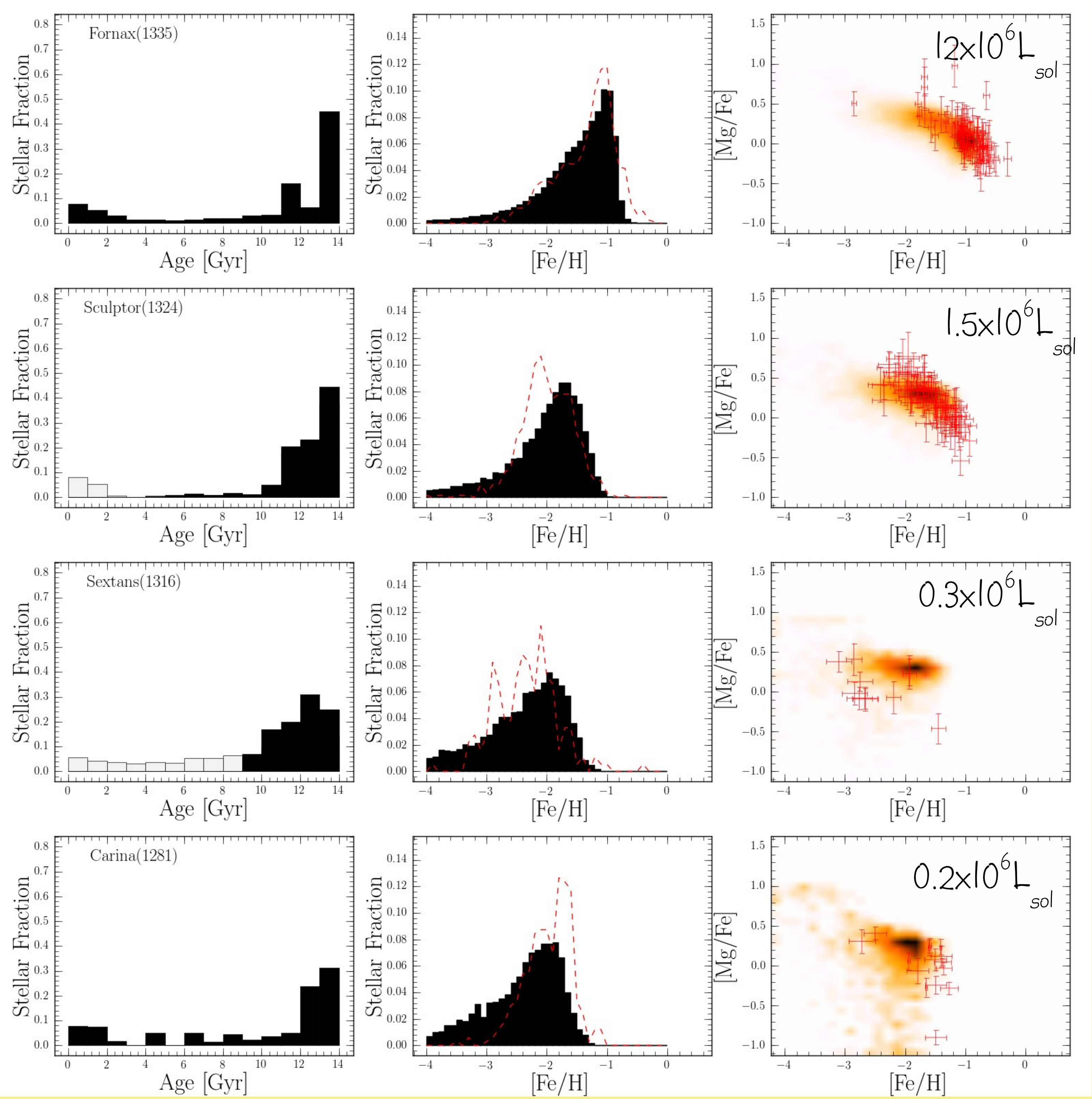


Fornax
$7\times10^8 M_{sol}$
6×10^{-2} a/cm^3

Sculptor
$5\times10^8 M_{sol}$
3×10^{-2} a/cm^3

Sextans
$3\times10^8 M_{sol}$
2×10^{-2} a/cm^3

Carina
$1\times10^8 M_{sol}$
2×10^{-2} a/cm^3



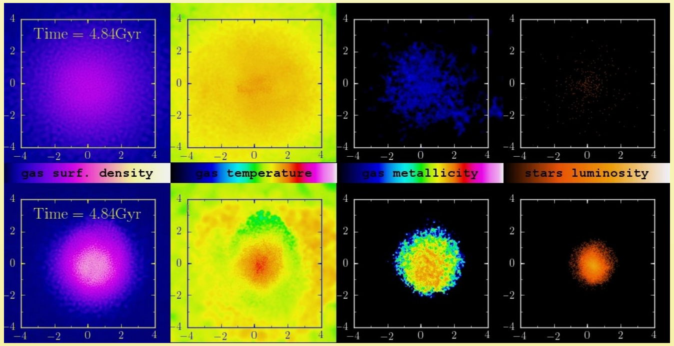
What do we learn from the models ?

- dSphs may be understood as a sequence of mass/density (internal processes)
  - More massive and dense systems, form stars continuously
    - ⟶ high [Fe/H] ⟶ high Lv
  - Less massive and less dense sytems forms stars episodically
    - ⟶ low [Fe/H] ⟶ low Lv

But gas remains, and we need to get rid of it

- Increase the feedback ? NO !
  - To fit the dSphs metallicity, SNs feedback cannot be large (no strong winds)

- External physical processes
  - tidal stripping ?
  - ram pressure stripping ?
  - encounters ?

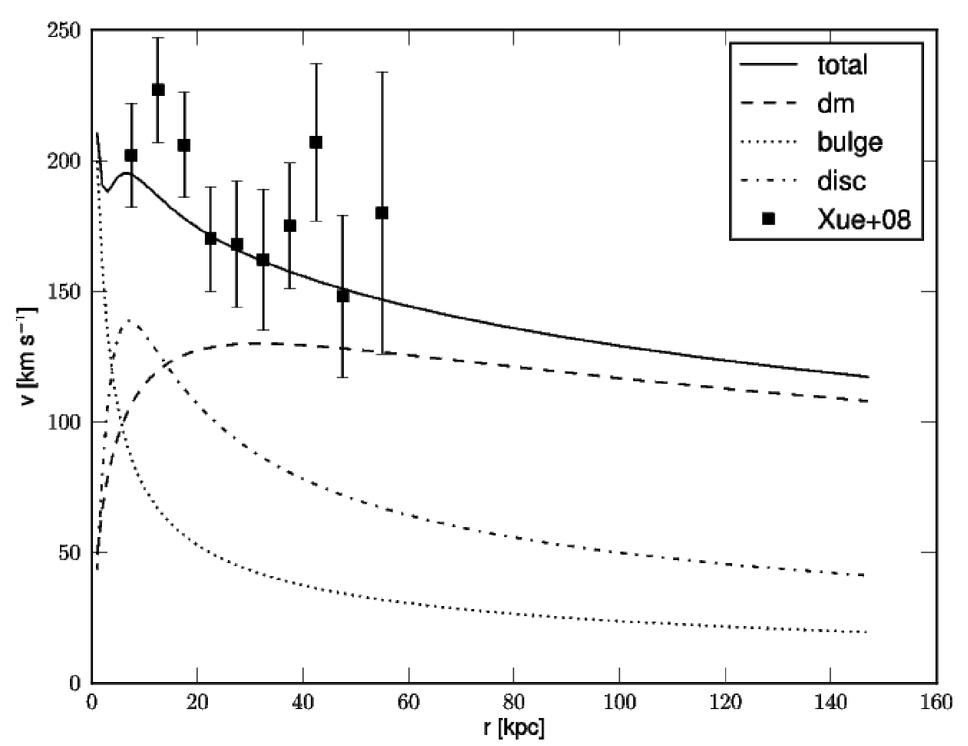


Tidal stripping

Tidal Stripping

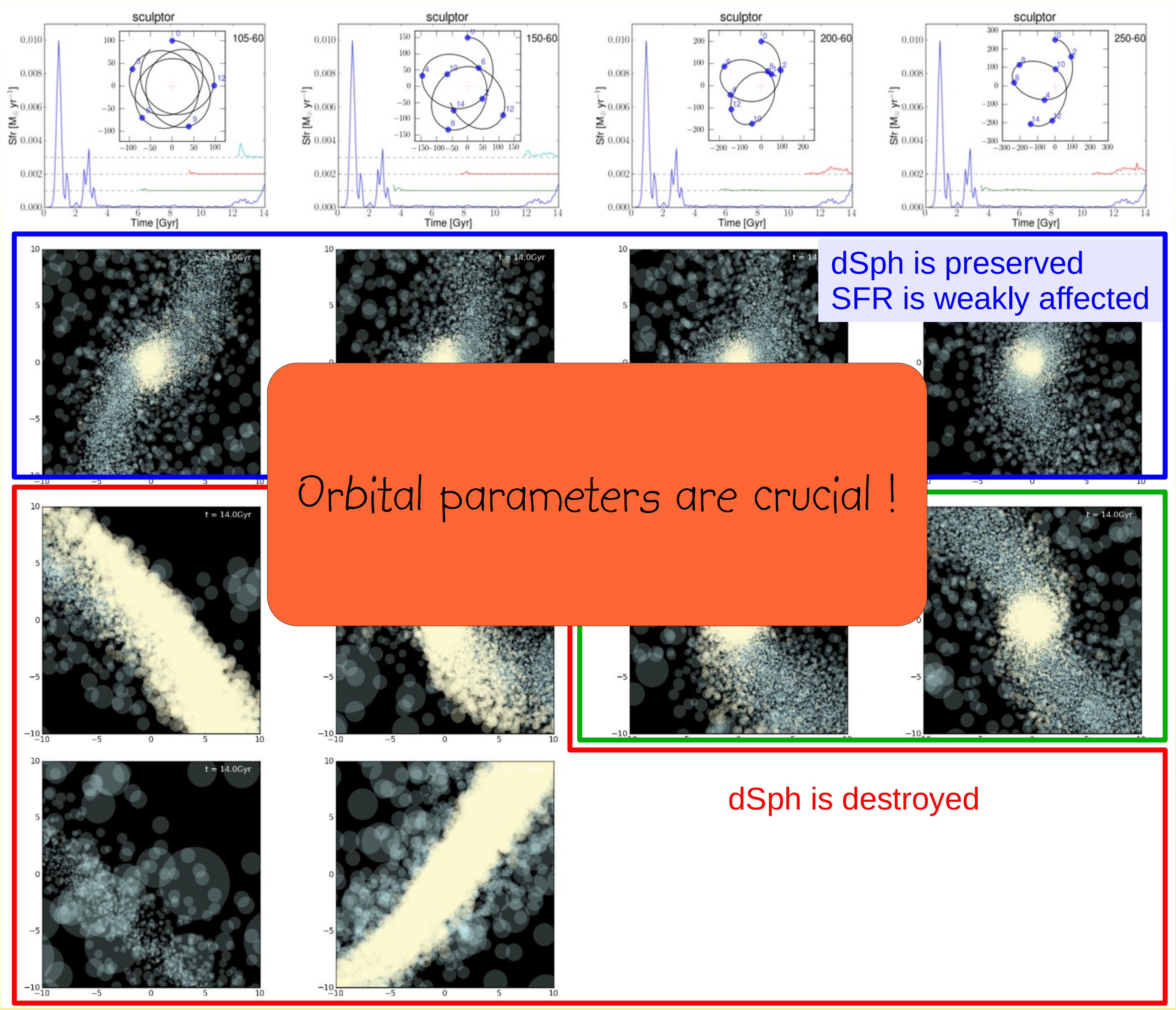
(Tiret et al. in prep.)

- dSph are launched in a fixed potential
  - halo : NFW 4×10^{11} Msol
  - bulge : Plummer 1.3×10^{10} Msol
  - disk : Miyamoto-Nagai 5.8×10^{10} Msol



- Orbital parameters are varied
  - apocenter, pericenter, number of orbits

What is the effect on the star formation history ?


sculptor
105-60
150-60
200-60
250-60
Sfr [M⊙ yr⁻¹]
Time [Gyr]
t = 14.0Gyr
dSph is preserved
SFR is weakly affected
Orbital parameters are crucial !
dSph is destroyed

The role of GAIA

Proper motions of dSph

- Order of magnitude of the proper motions
  - Distance 100 Kpc
  - Velocity 10 Km/s

→ proper motion of 100 μas over 5 yrs

GAIA accuracy : 25 to 300 μas

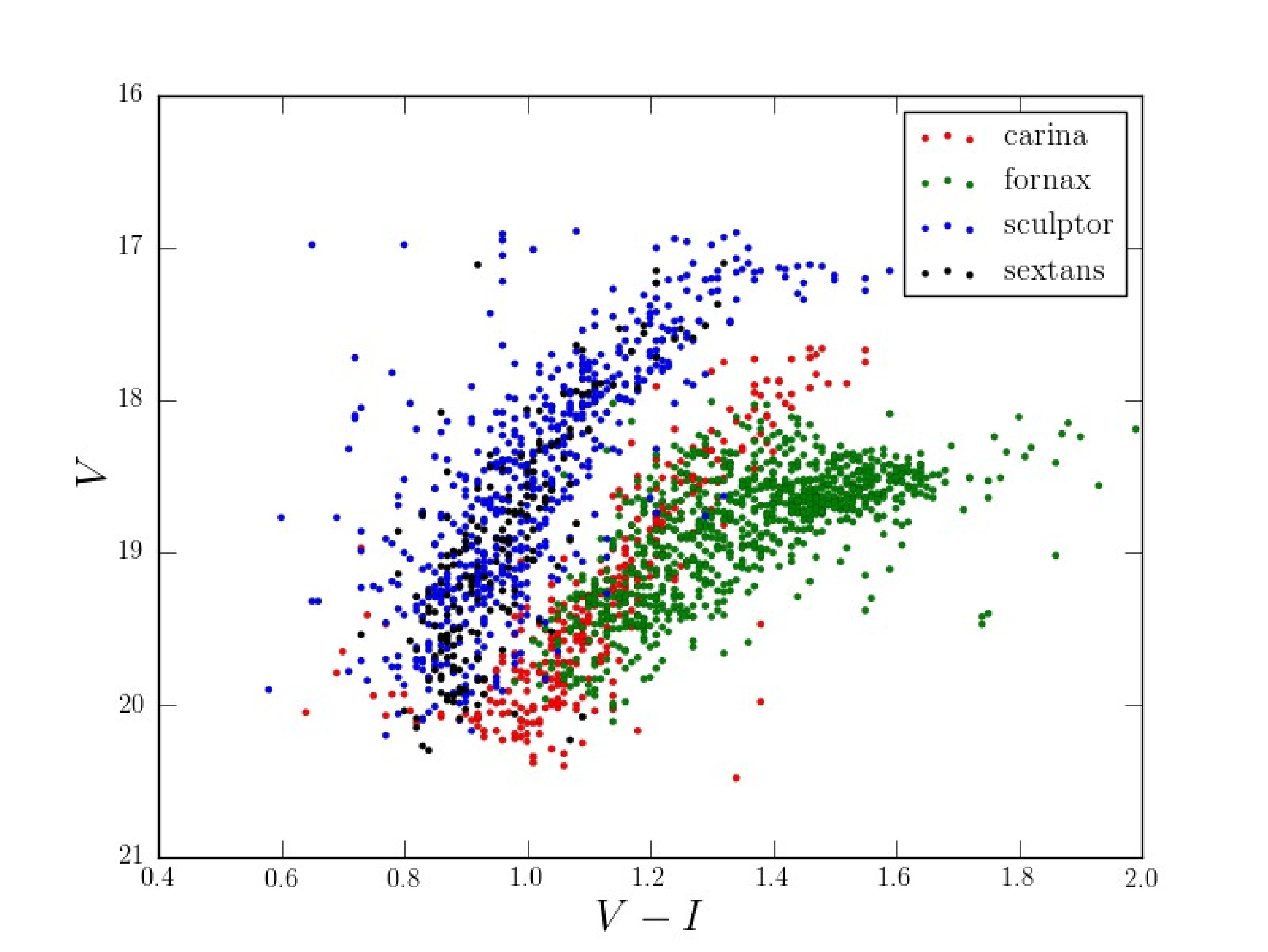
But depends strongly on
- the V-magnitude of the star
- the V-I index

$$\sigma_\pi\,[\mu as] = (9.3 + 658.1 \cdot z + 4.568 \cdot z^2)^{1/2} \cdot [0.986 + (1 - 0.986) \cdot (V\text{-}I_C)],$$

$$G = V - 0.0257 - 0.0924 \cdot (V\text{-}I_C) - 0.1623 \cdot (V\text{-}I_C)^2 + 0.0090 \cdot (V\text{-}I_C)^3,$$

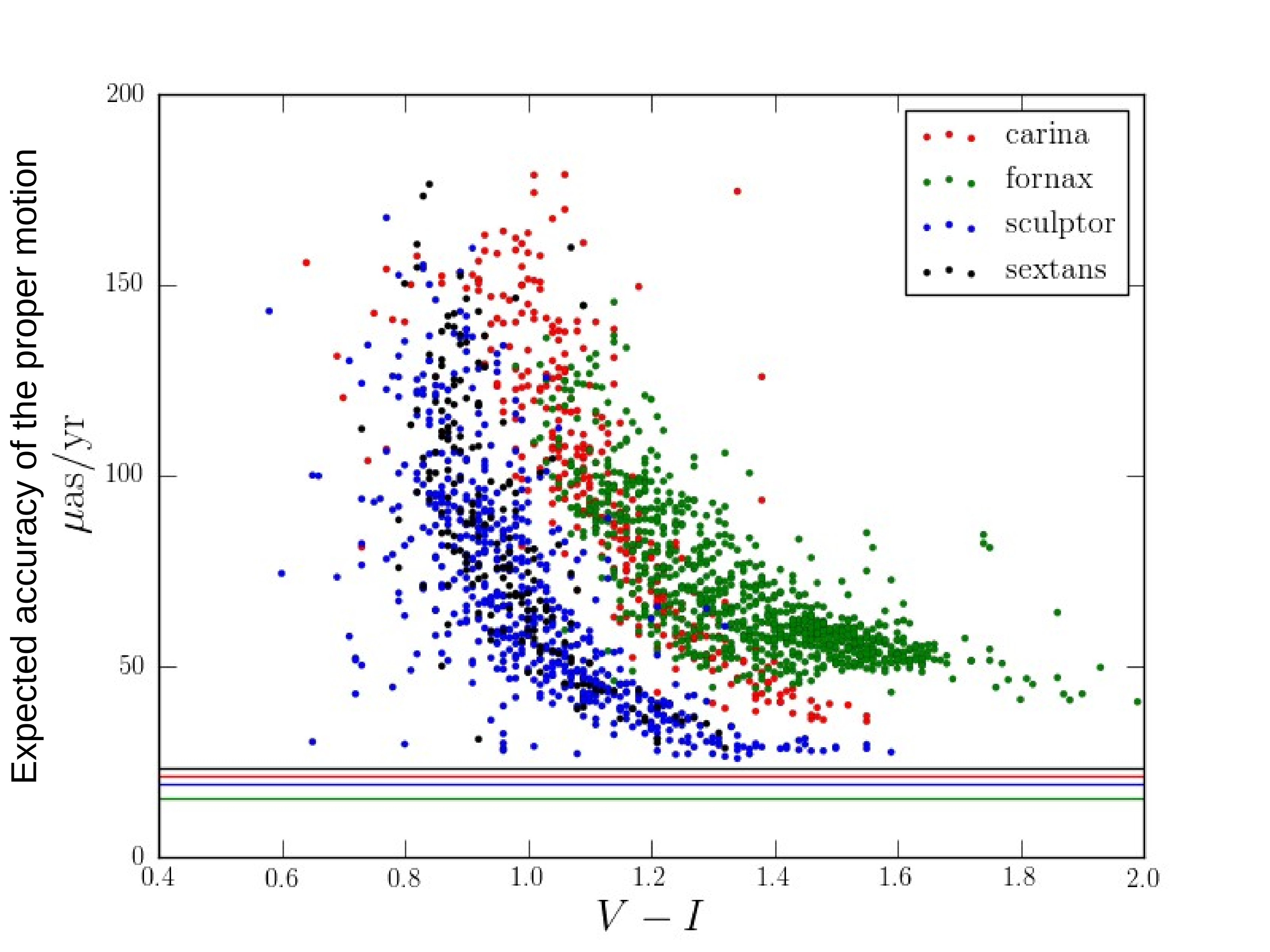
$$z = \mathrm{MAX}[10^{0.4 \cdot (12 - 15)}, 10^{0.4 \cdot (G - 15)}],$$

Properties of stars in dSph systems (Carina, Fornax, Sculptor, Sextans)

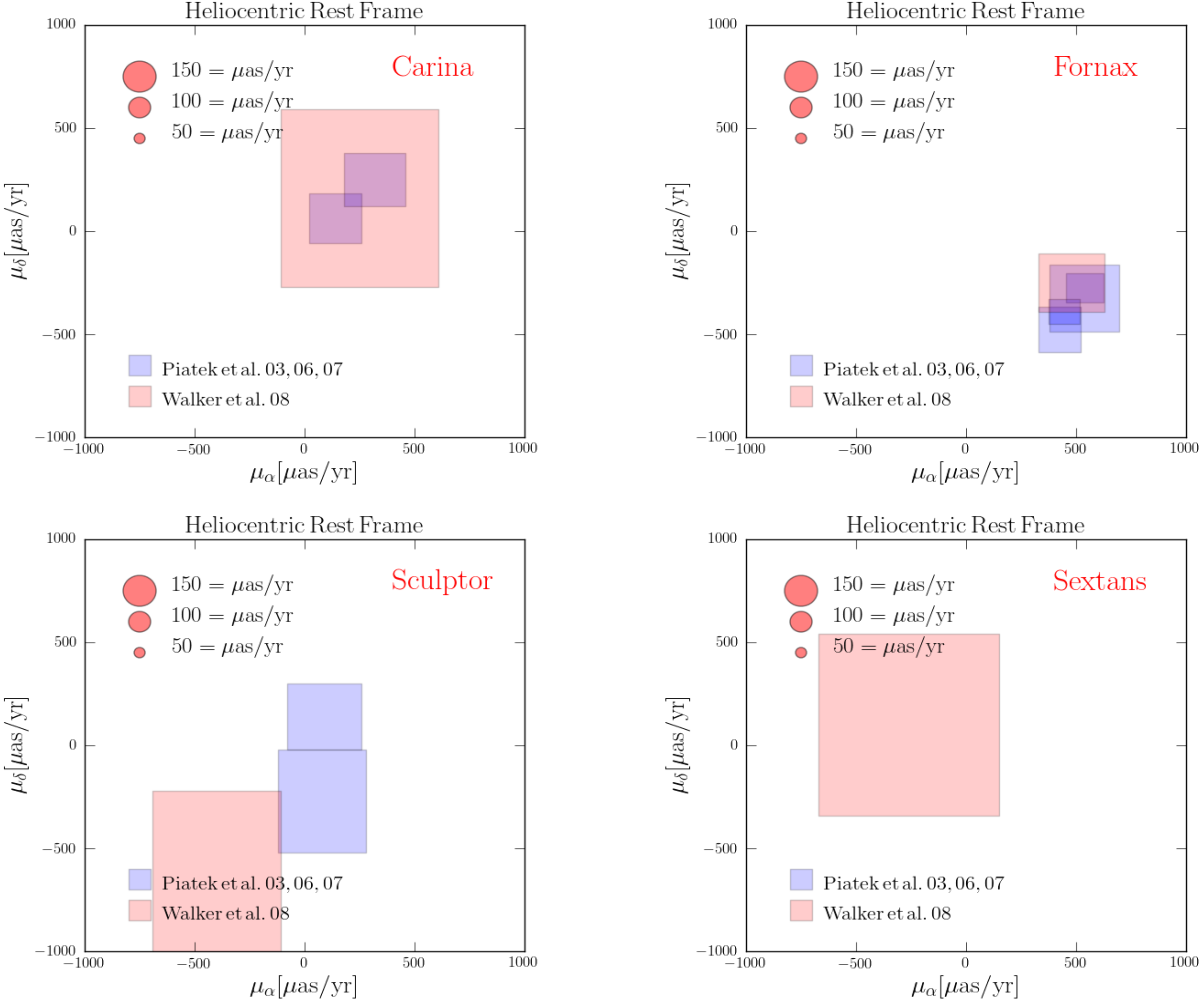


Data from DART observations

Properties of stars in dSph systems (Carina, Fornax, Sculptor, Sextans)



Data from DART observations


Heliocentric Rest Frame
Carina
150 = µas/yr
100 = µas/yr
50 = µas/yr
Piatek et al. 03, 06, 07
Walker et al. 08
$\mu_\alpha[\mu as/yr]$
$\mu_\delta[\mu as/yr]$
Heliocentric Rest Frame
Fornax
150 = µas/yr
100 = µas/yr
50 = µas/yr
Piatek et al. 03, 06, 07
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$\mu_\alpha[\mu as/yr]$
$\mu_\delta[\mu as/yr]$

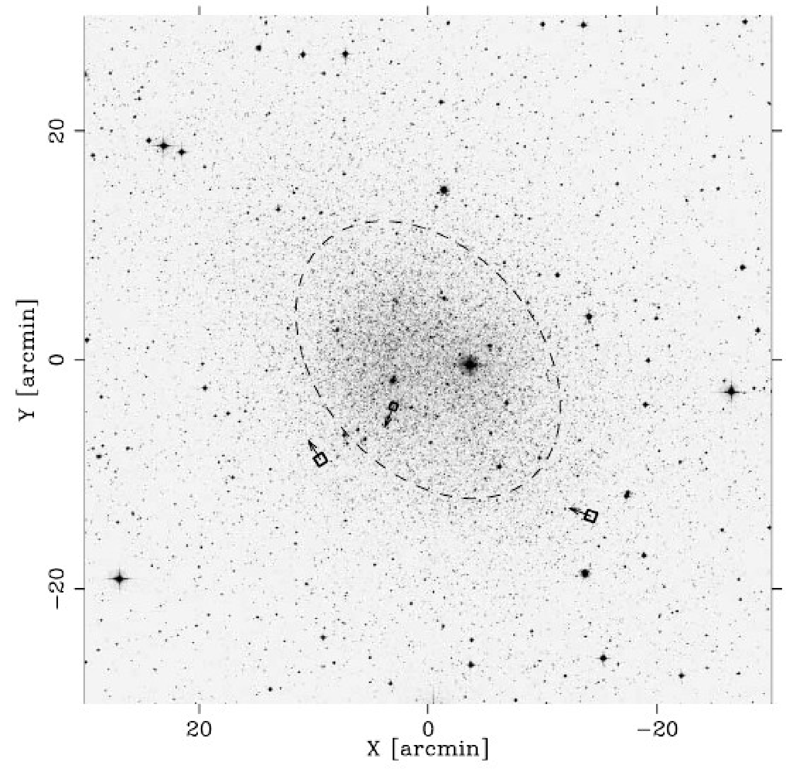
Other advantages of GAIA

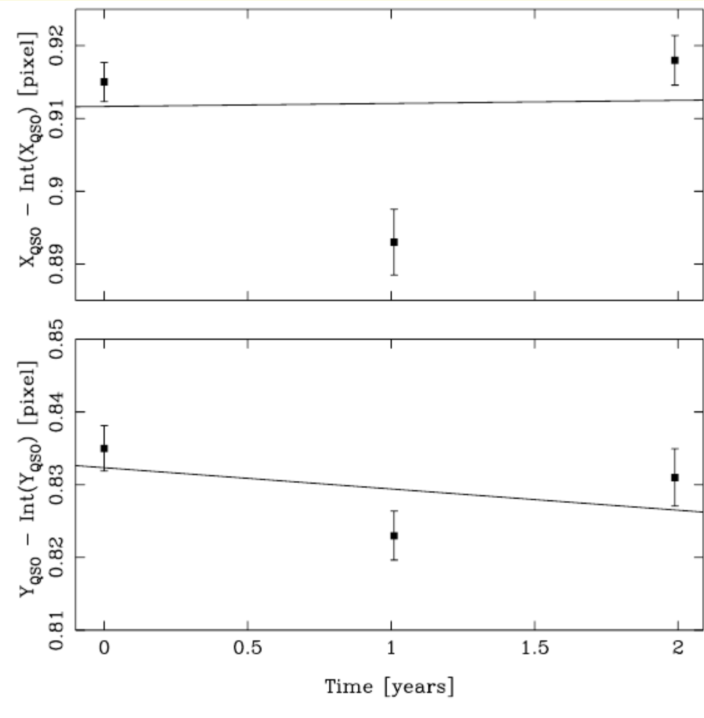
Piatek et al.03,06,07

- 2-3 small field of view (< arc min)
- 3 measures over 2-3 years
- only 1 reference source (QSO)

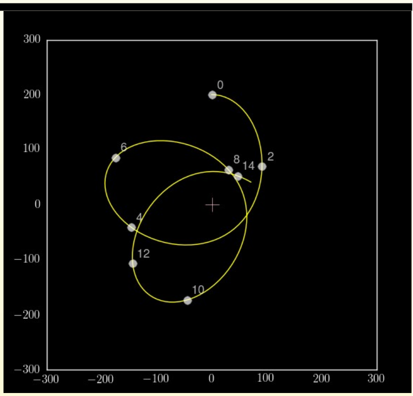
GAIA

- full coverage
- about 70 measures over 5-6 years
- Full sky calibration





The determination of the orbital parameters



1) proper motions -> space velocities in the galacto-centric rest frame
2) setup of a galactic potential (ex. Law et al. 2005)
3) launch orbits, including velocity errors

Lux et al. 2010

- last apocenter and pericenter to about 14% (instead of 40%)
- recovering the full 3d orbit is more difficult

Reach a level where errors are no longer dominated by proper motions uncertainties, but by the modelling :

- potential shape
- time variation of the potential
- dynamical friction
- satellites mass loss
- interactions

Conclusions

- dSphs galaxies constitute an excellent test for cosmological paradigms, in particular for the LCDM model

- Self-consistent modelisation tells us that :
  - The diversity may be explained by intrinsic factors (mass/density)
  - Extrinsic processes are needed to get rid of the gas

- Tidal stripping can quench the star formation, but this depends strongly on the orbital parameters of the dSph

- GAIA will definitively improve the determination of the orbital parameters