Chemistry and kinematics of stars in Local Group galaxies

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In collaboration with DART

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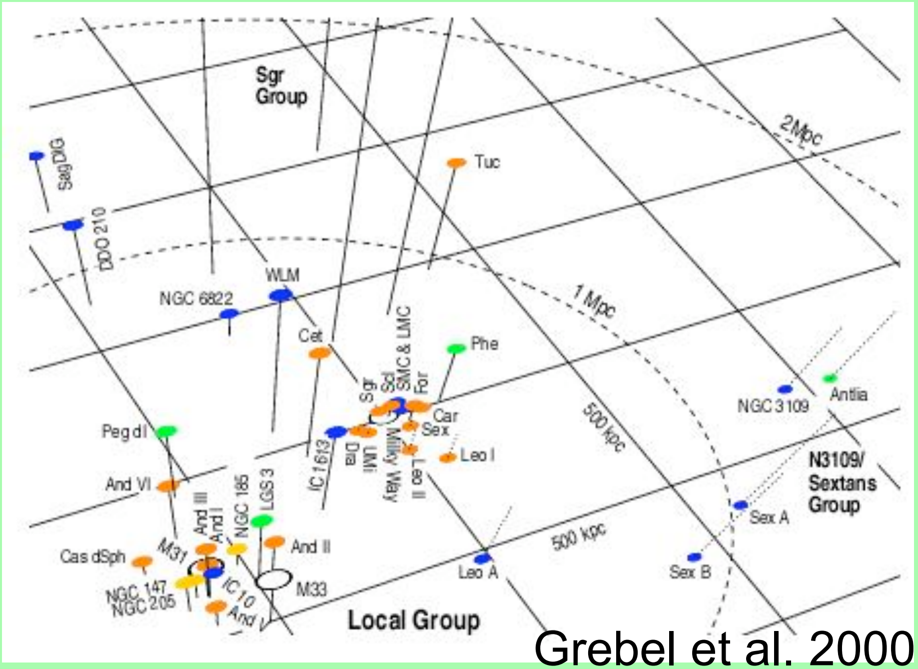
Dwarf spheroidal galaxies

Small (half-light radius= 0.1-1kpc), devoid of gas, pressure supported

Motivation

- Galaxy formation on the smallest scales
  - Evolution and distribution of stellar populations
  - Chemical enrichment histories
  - All dSphs contain > 10 Gyr old stars => early universe
- Most dark-matter dominated galaxies
  - Measure dark-matter distribution
  - Constrain the nature of dark-matter (warm, cold...)
- Galaxy formation: building blocks of large galaxies?

The Local Group



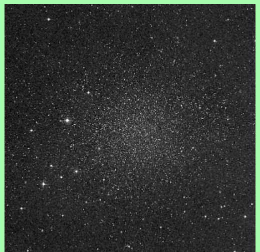
Grebel et al. 2000

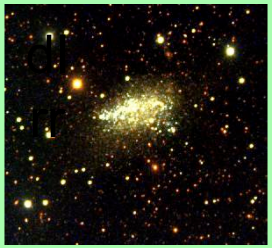
Large spirals

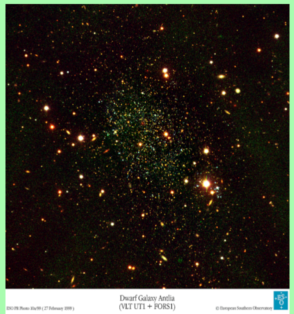
Dwarf ellipticals (dE); dwarf spheroidals (dSphs)

Dwarf irregulars (dIrr)

dSphs/dIrrs







Large majority

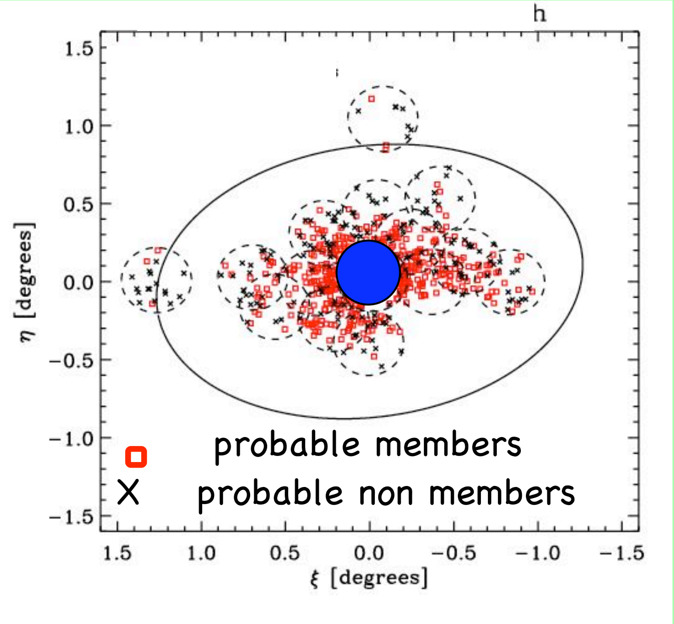
DART Large Program at ESO

- 4 dSphs in the MW halo: Sextans, Sculptor, Fornax, Carina (HR only)

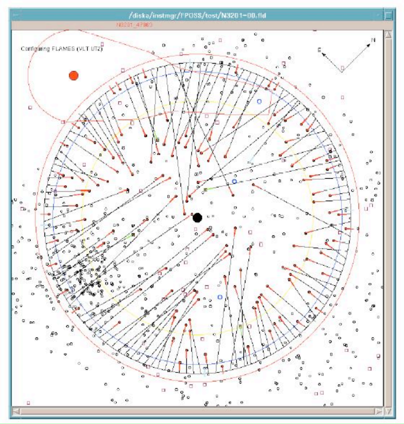
- Extended ESO/WFI imaging (CMD)

- VLT/FLAMES Low Resolution (LR) spectra of 100s **Red Giant Branch (RGB) stars in CaII triplet (CaT) region** over a large area
  => vel & [Fe/H]

- VLT/FLAMES High Resolution (HR) spectra (~ 100 stars) in central regions (abundances of many elements)



25 arcmin



Outline

1) Sculptor & Fornax: similarities and differences

- Properties of stellar populations from CMD analysis
- Kinematic and metallicity general properties from CaT LR

2) Mass determination of the Sculptor dSph

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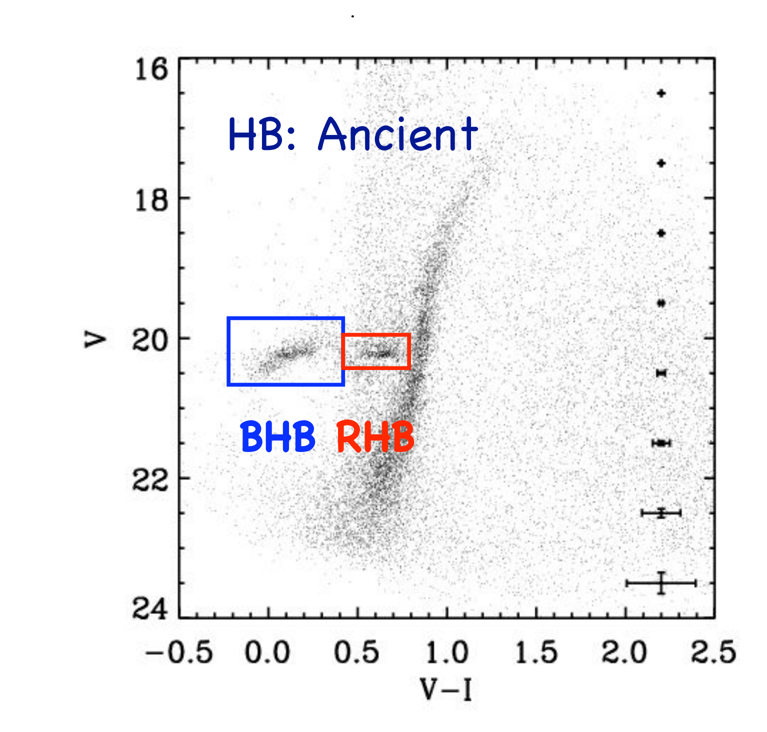
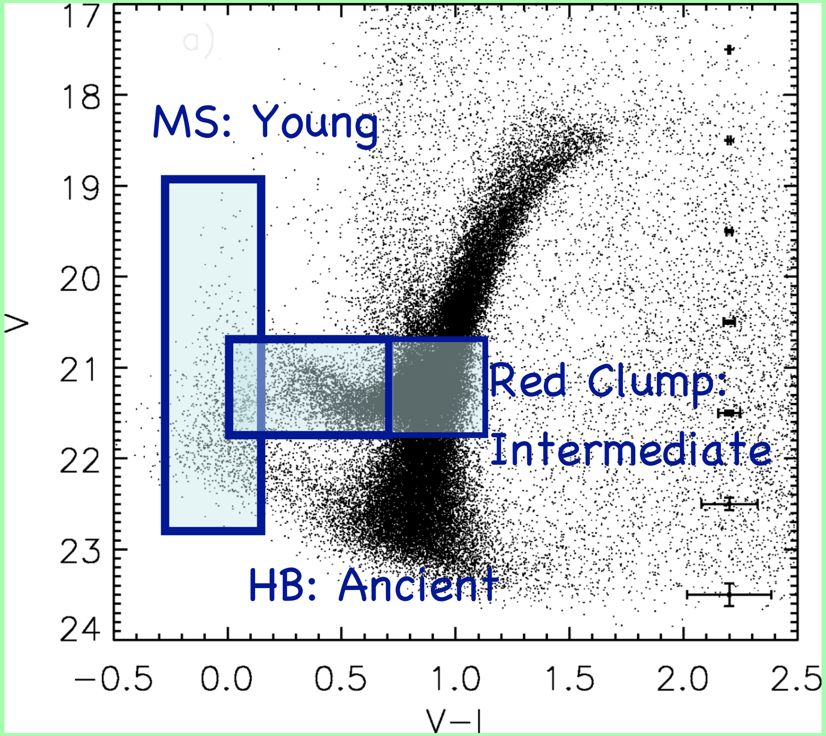
ESO/WFI photometry:
Sculptor vs Fornax



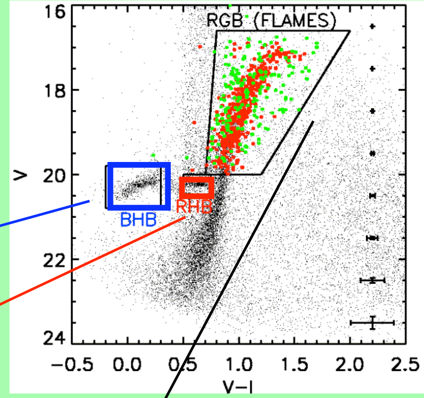


Ancient: > 10 Gyr old

Intermediate: 3-6 Gyr old

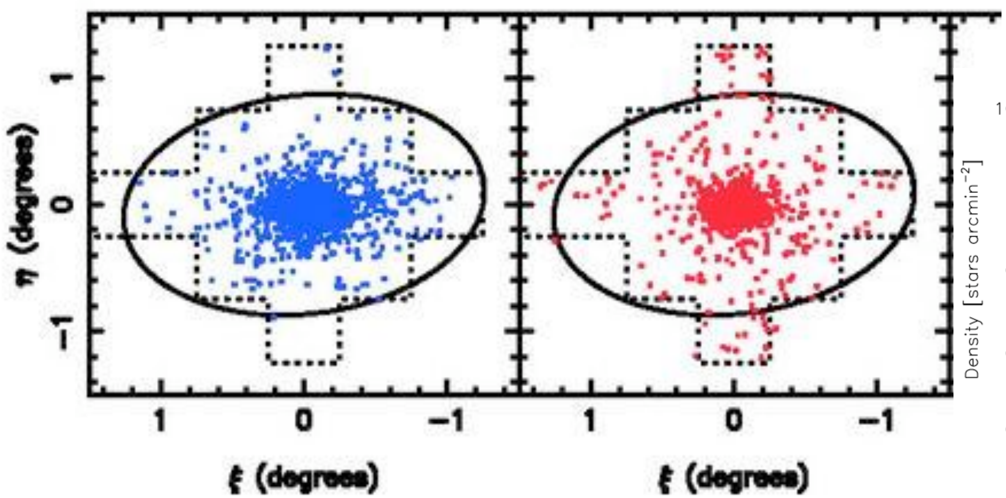
Young: < 1 Gyr old

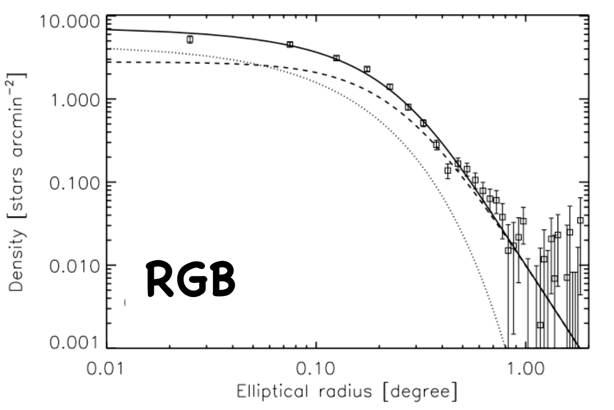
Spatial variation of stellar population: Sculptor



Tolstoy et al. (2004)

BHB > 10 Gyr old **RHB > 10 Gyr old**



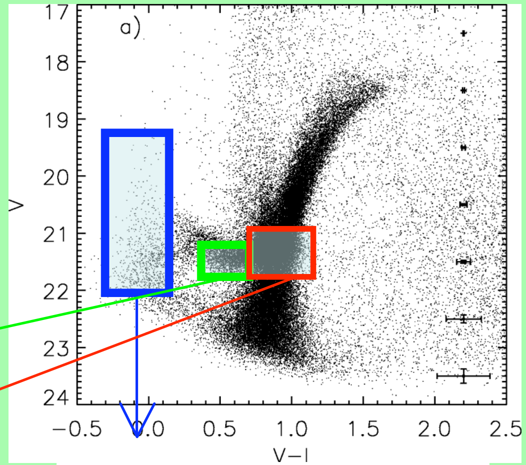


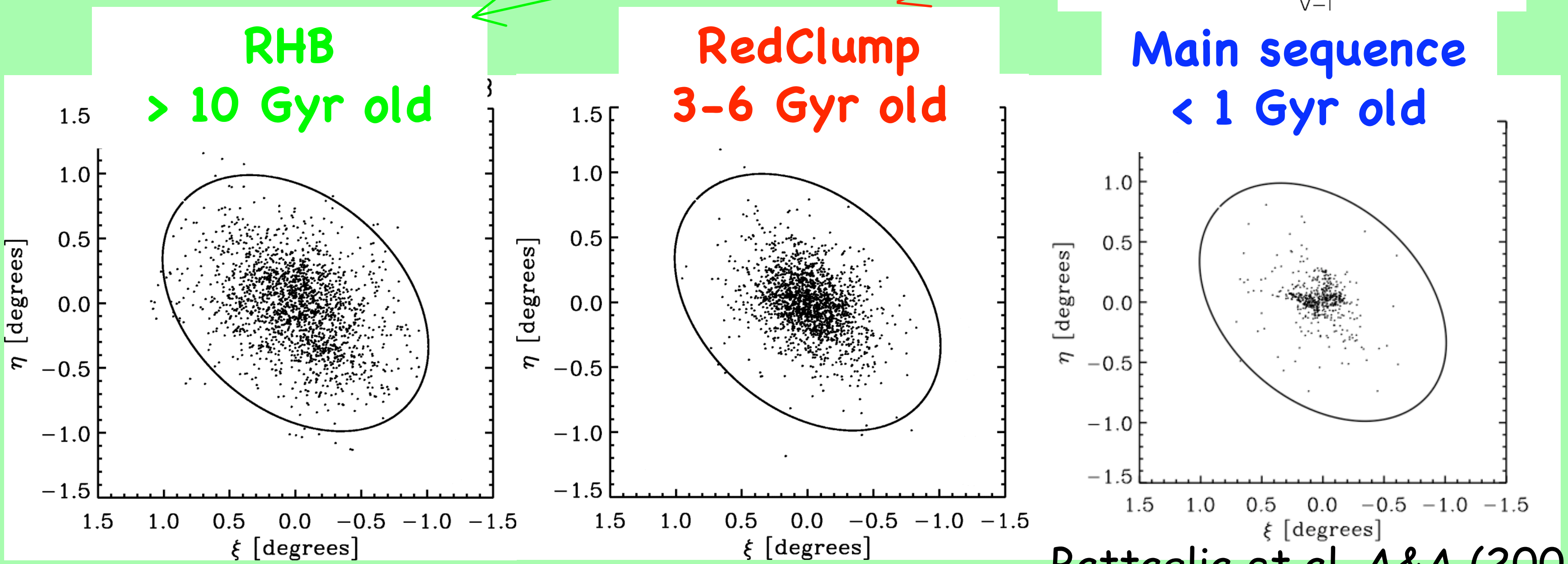
BHB: more extended
Best fit by
Plummer law

RHB: centrally
concentrated
Best fit by
Sersic profile

RGB: composite profile
(BHB+RHB) provides good
fit to data

Spatial variation of stellar population: Fornax





Battaglia et al. A&A (2006)

Intermediate age stars (RC, 3-6 Gyr) less extended and more centrally concentrated than old stars (RHB, >10 Gyr)

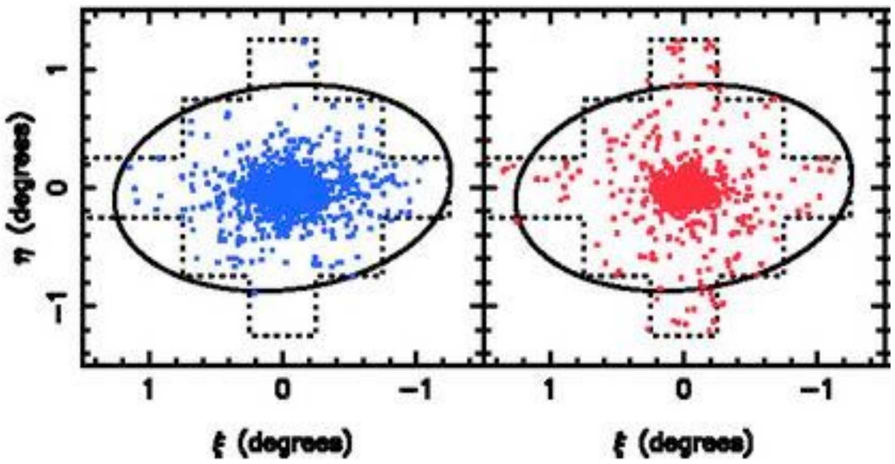
Young stars (MS, < 1 Gyr) centrally concentrated with asymmetric distribution (see also Stetson et al.1998)

Summary I

Spatial variations of stellar populations are present both in Scl and Fnx

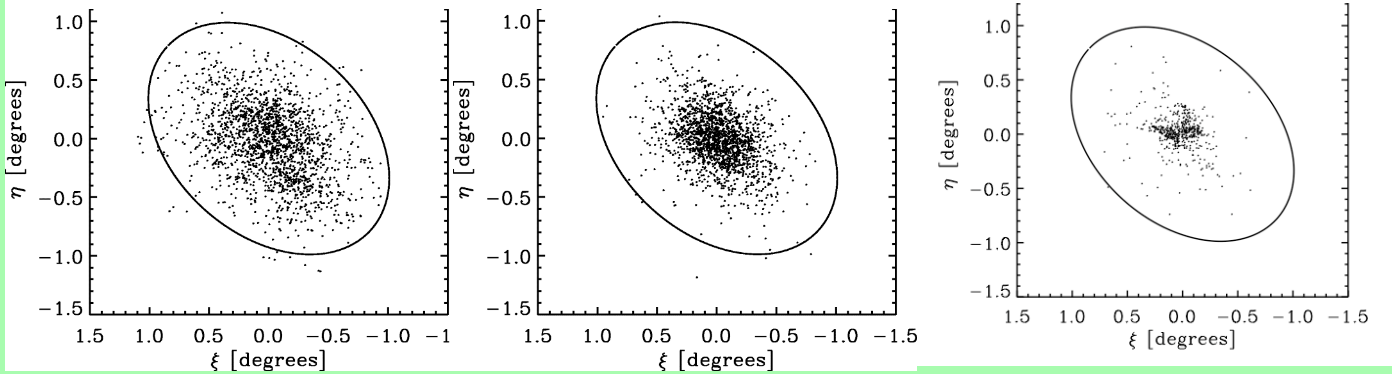
Scl

> 10 Gyr old | > 10 Gyr old



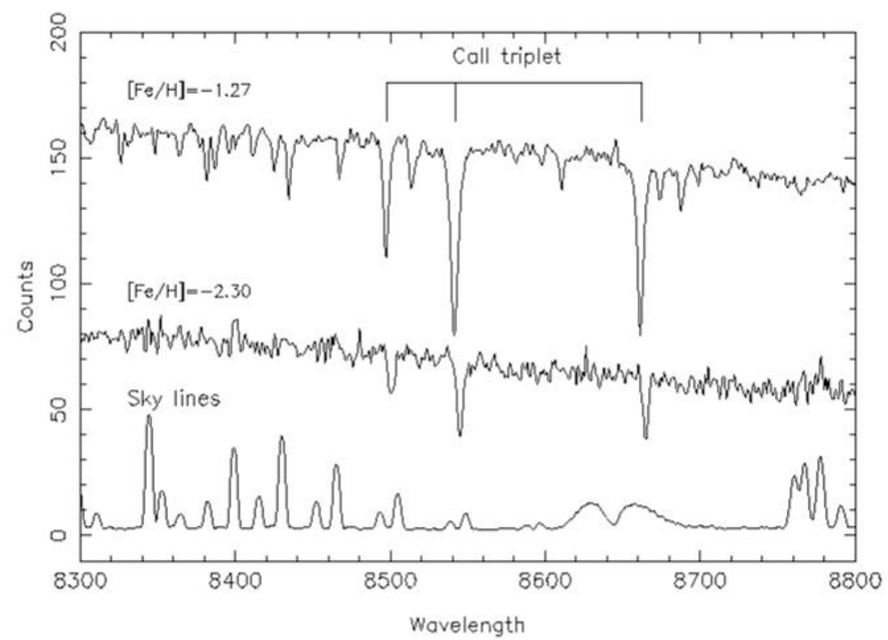
Fnx

> 10 Gyr old | 3-6 Gyr old | < 1 Gyr old



but for different age ranges

LR around Ca II Triplet (CaT)



Tolstoy et al. 2001

3 CaT lines at ~ 8500Å give:

1) accurate line-of-sight velocities: δv_r ~ 2 km/s (S/N = 20)

2) Calibration between CaT EW and [Fe/H] allows metallicity determination with errors δ[Fe/H] ~ 0.1-0.2 dex

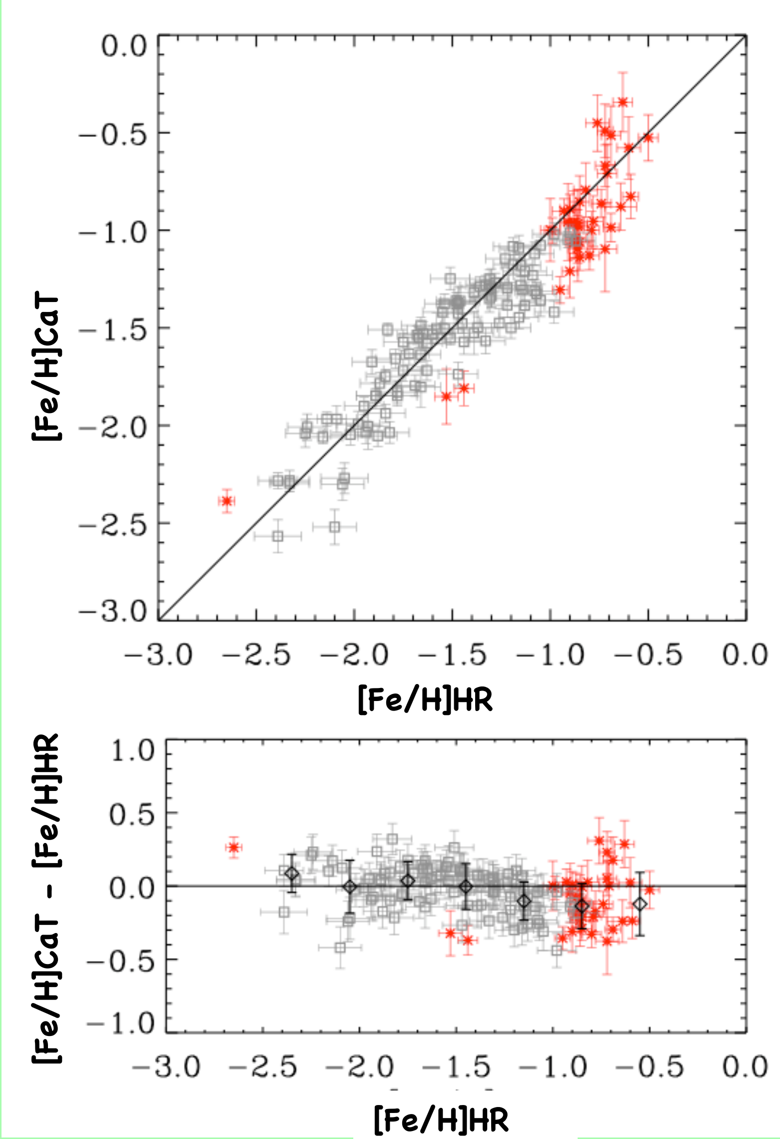
=> [Fe/H] not directly measured

We need to check that CaT-[Fe/H] calibration works

Check: LR(CaT) vs HR(direct) [Fe/H]

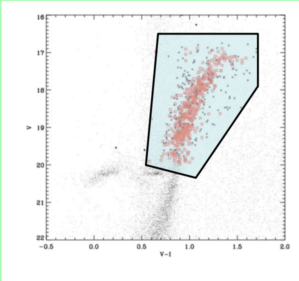
- Overlapping stars: 93 in Scl, 36 in Fnx
- Present a trend with metallicity
- Overall comparison good

Calibration also explored using synthetic stellar spectra from Munari et al. (2005)

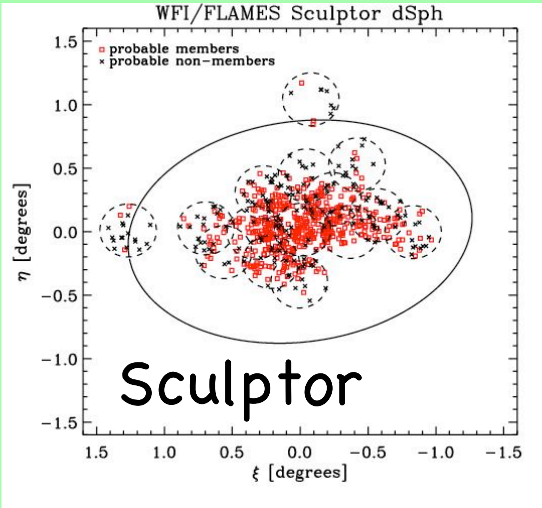


Battaglia et al. 2007, MNRAS, in press

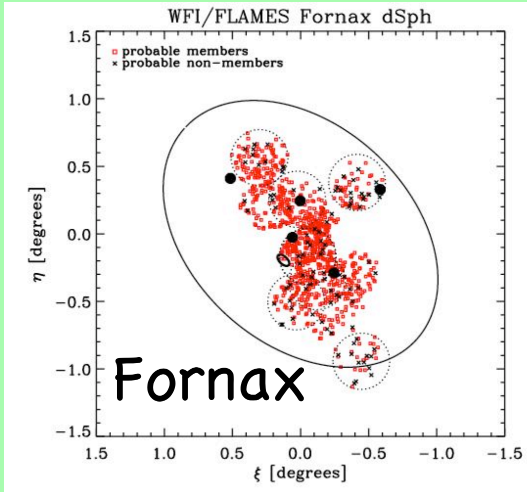
Overview of VLT/FLAMES LR data



Targetted
RGB stars



Tolstoy et al.(2004) + 7 new fields

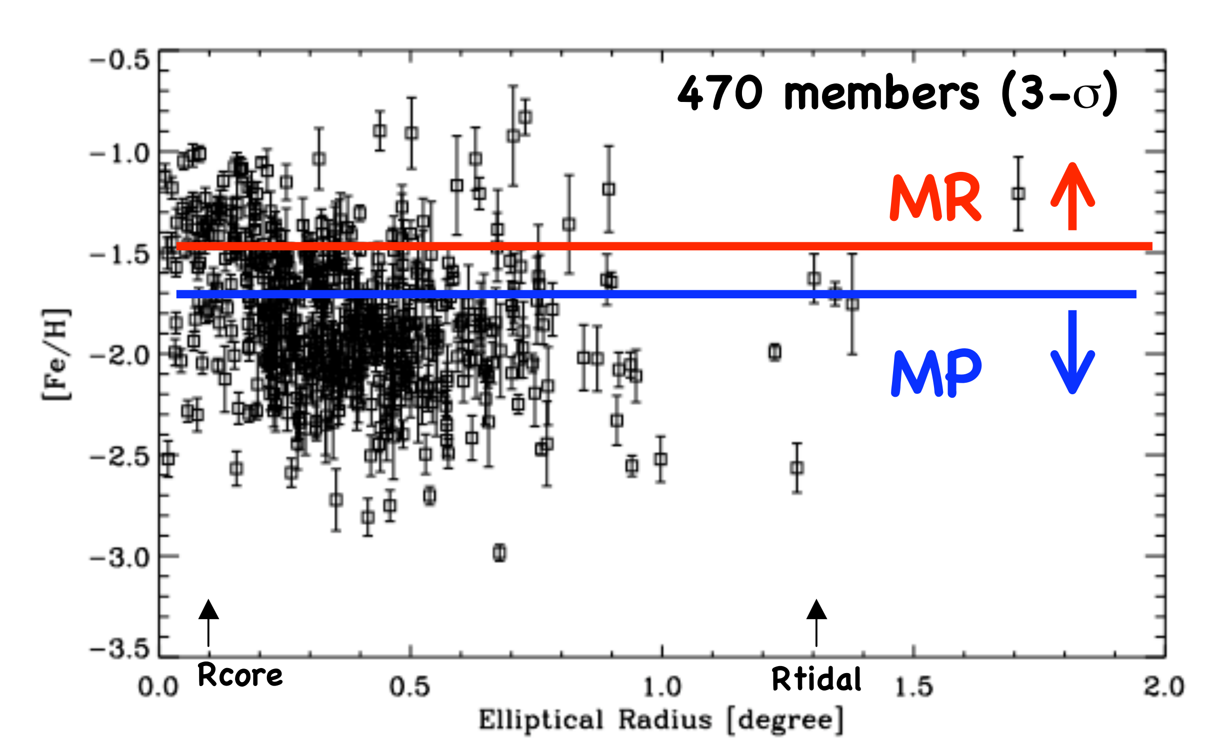


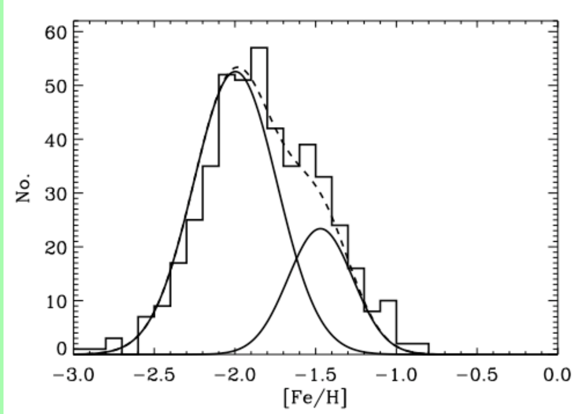
Battaglia et al.(2006) + 4 new fields

- Applied S/N, error in velocity, visual inspection criteria
- Probable Membership from simple velocity selection

- # Targets: 1013 1063
- Final sample: 648 stars 944 (in this talk 641 stars)

Chemo-dynamics: Sculptor



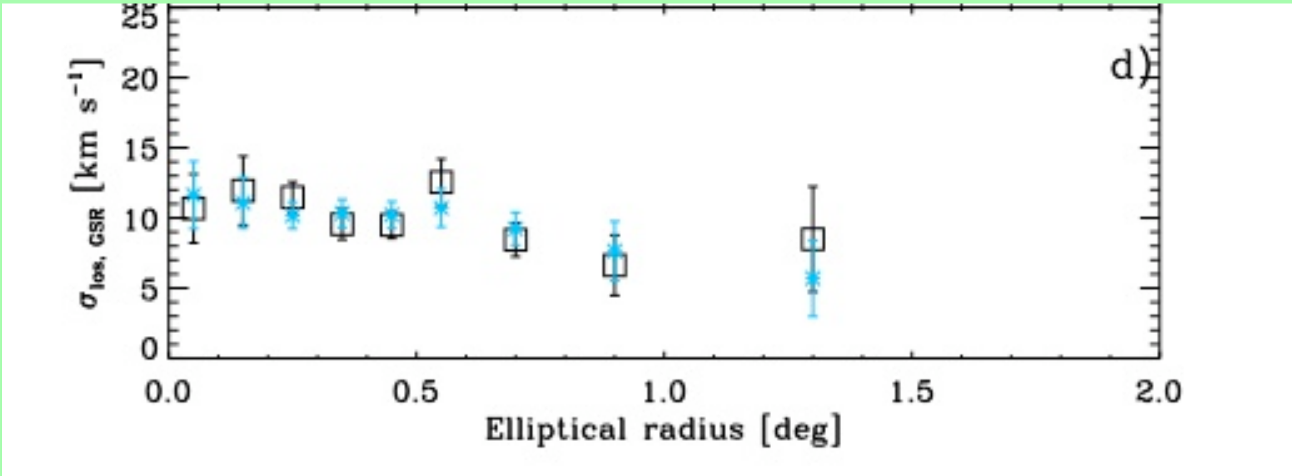


Metallicity variation with radius on the same scale as RHB/BHB variation

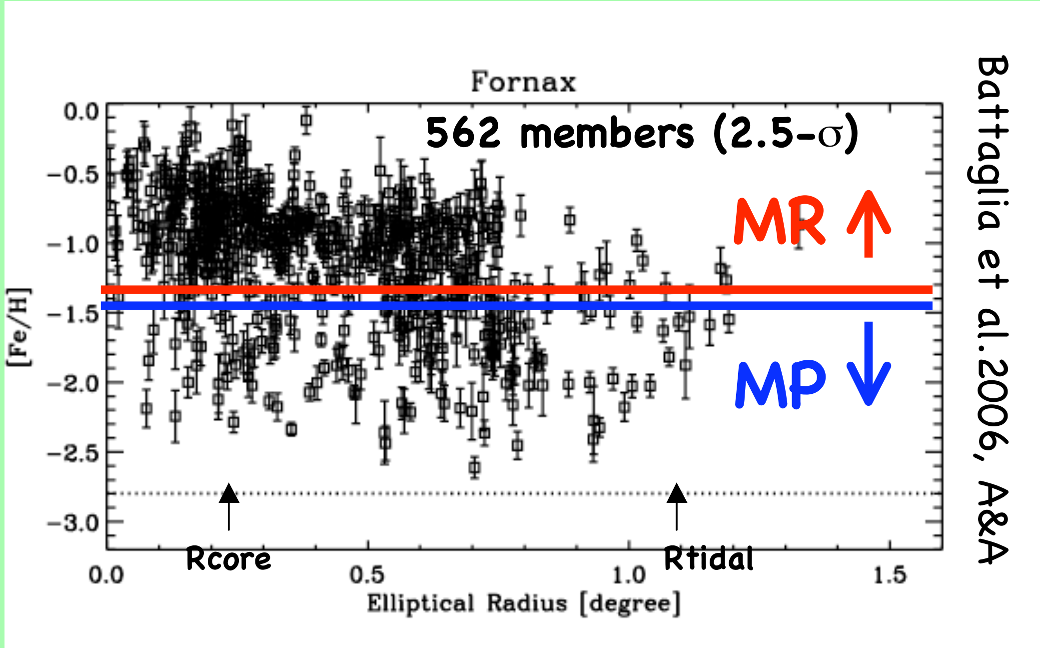
And it correlates with kinematics...

MR - - -

MP ....



Chemo-dynamics: Fornax

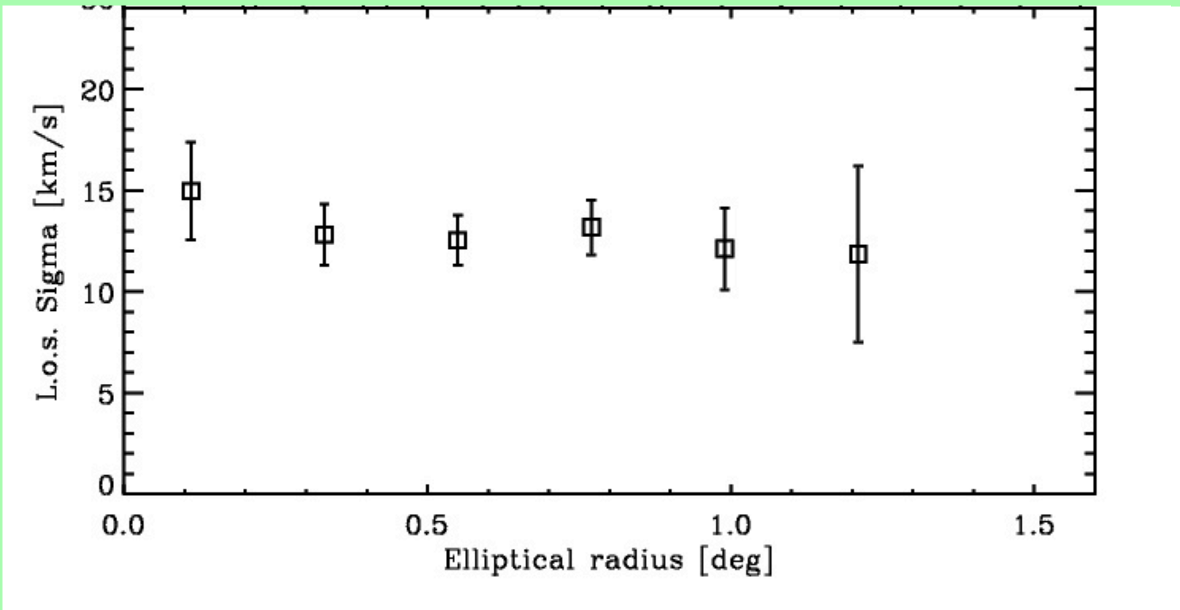


Metallicity variation w radius:

- Metal poor stars (>10 Gyr old) found throughout the galaxy
- Metal rich stars (3-6 Gyr old) mostly at r < 0.7 deg. They represent the large majority.
- Stars with [Fe/H] < -0.7 (1-2 Gyr old) at r < 0.4 deg

And it correlates with kinematics

MR - - -
MP ………



Summary II
On the evolution of Scl and Fnx: similarities

- MP/older stars are spatially extended;
  MR/younger stars are more centrally concentrated
  =>Removal of Gas/metals from the outer regions

- Different kinematics for different metallicity components in both Scl and Fnx
  => due to readjustment of the location where star formation took place?

Summary II
On the evolution of Scl and Fnx: differences

Scl

(Formed stars until 10 Gyr ago)

- MP stars dominant (70%) =>First phase of SF more intense
- Efficient removal of gas/metals on a short time scale

Fnx

(Formed stars until 200 Myr ago)

- Intermediate age (3-6 Gyr old)/MR stars (57%) dominant => first phase of SF not very intense
- Slower removal of gas/metals

If Scl is less massive than Fnx supernovae explosions, ram pressure, tides might be more efficient

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1) Sculptor & Fornax: similarities and differences

- Properties of stellar populations from CMD analysis
- Kinematic and metallicity general properties from CaT LR

2) Mass determination of the Sculptor dSph

Determination of the Sculptor mass content and distribution

- **Importance:**
  mass might drive star formation and chemical enrichment processes; useful to test different DM theories

- **Method:**
  observed l.o.s. velocity dispersion profiles for MR and MP stars are compared to predictions from different DM models (using Jeans equation)

System must be in equilibrium!

(tidal disruption could inflate measured dispersion)

We do not find signs of tidal disruption in Sculptor

Predicted velocity dispersion from Jeans equation

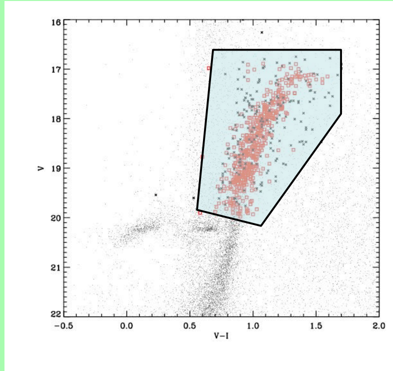
For stationary and spherically symmetric systems

$$\sigma_{\rm los}^2 = \frac{2}{\Sigma_*(R)} \int_R^\infty V_c^2(y) y^{2\beta-1} \rho_*(y) H(y) dy$$

Line of sight velocity dispersion depends on:

- Spatial distribution of tracer population, $\Sigma_*(R)$, $\rho_*(r)$
- Velocity anisotropy of tracer population, $\beta(r) = 1 - \frac{\sigma_\theta^2}{\sigma_r^2}$
- Total potential, $V_c^2(r)$ or $\phi(r)$

Ingredients in the modeling



- Tracer:
  - Two components => MR and MP RGB stars, separately
- Tracer spatial distribution from WFI photometry
  - Two components => centrally concentrated Sersic (MR) & extended Plummer (MP) profiles
- Velocity anisotropy, β
  - constant
  - varying with radius as in Osipkov-Merritt $\beta(r)= r_a^2/(r^2+ r_a^2)$
    (isotropic in the centre, radial in the outskirts)
- Dark matter mass model
  - **CORED = Pseudo-Isothermal sphere:** $\rho(r) = \rho_0\ r_c^2/(r^2 + r_c^2)$
  - **CUSPY = NFW:** $\rho(r) = \rho_0/[r/r_s\ (1 + r/r_s)^2]$
- Best fit model obtained by minimizing $\chi^2_{MR} + \chi^2_{MP}$ (2 comp.)
- Beware of degeneracies, e.g. mass profile-anisotropy

Two components: ß constant

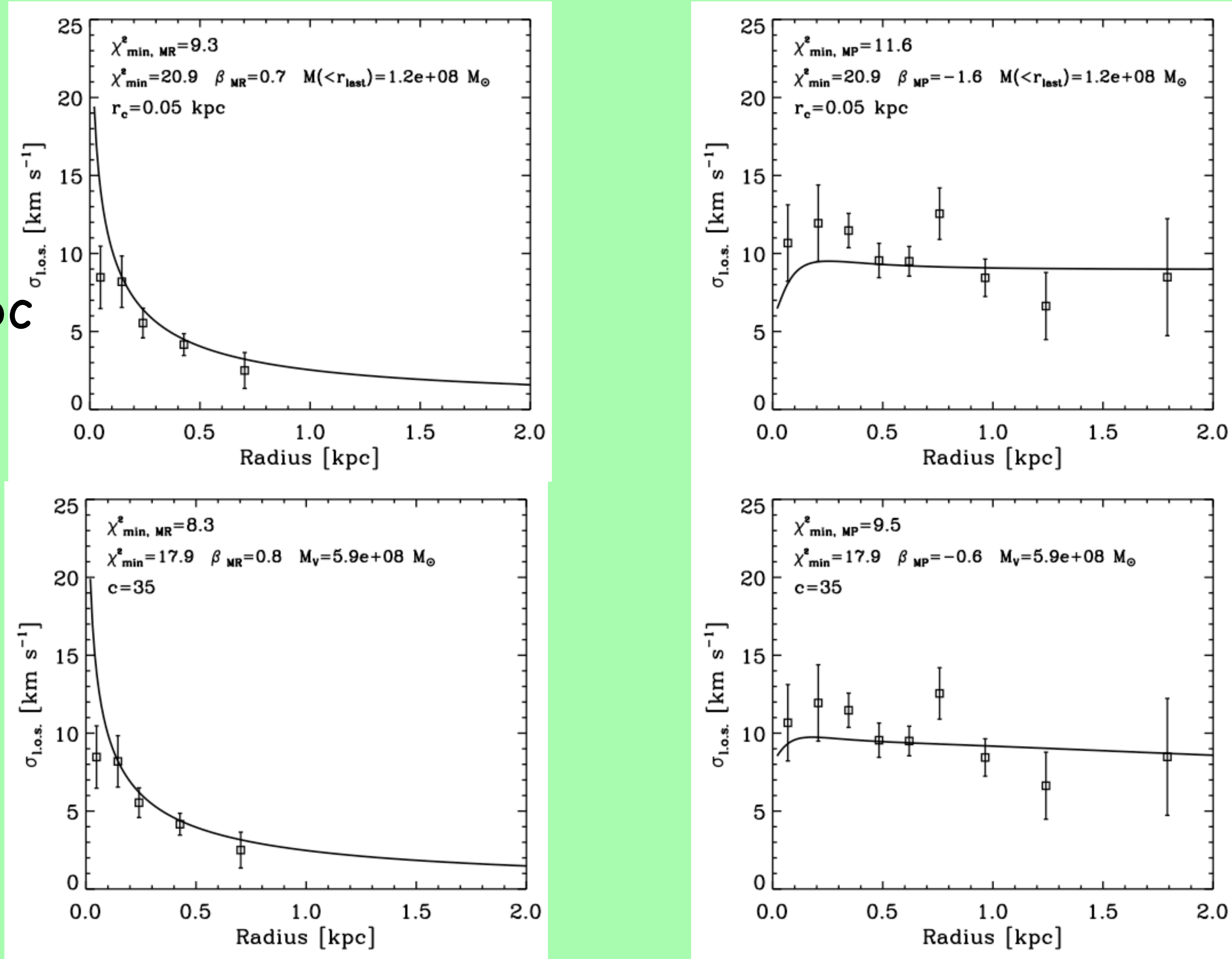
MR **MP**

Iso

rc=0.05kpc

NFW

c=35



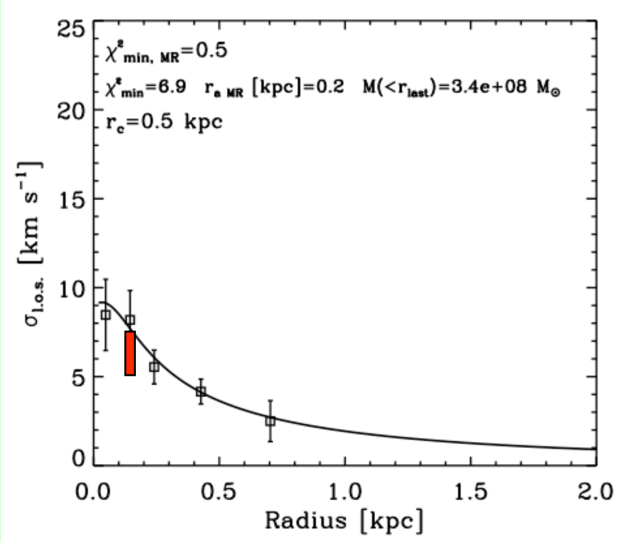
Both unsatisfactory (also when using ≠ rc and concentrations)

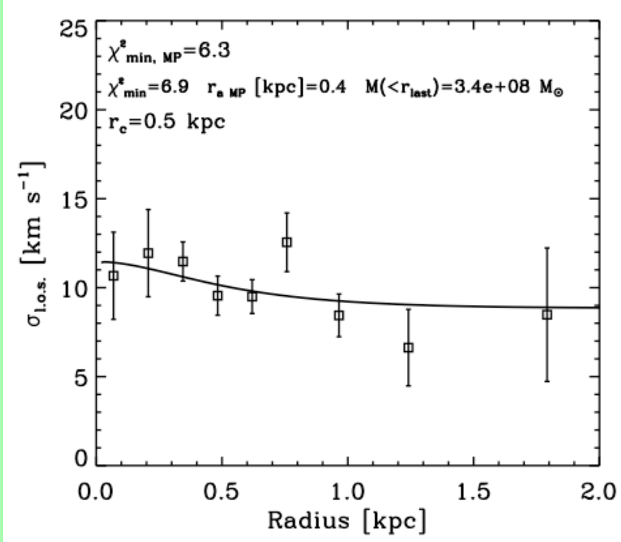
Two components: β_{OM}

MR **MP**

Iso

rc=0.5kpc

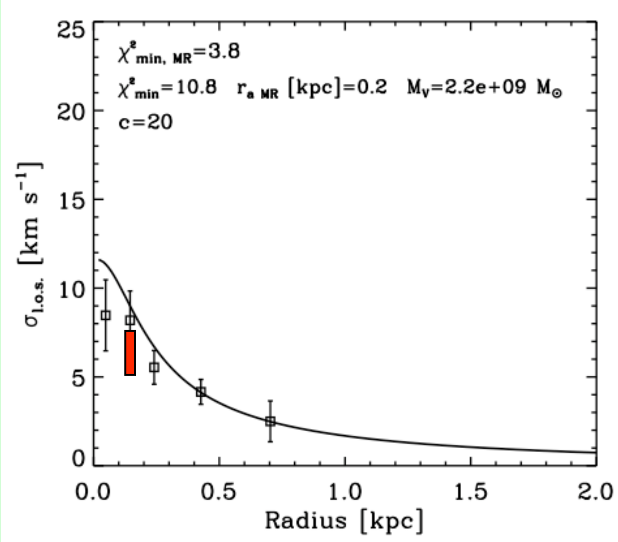


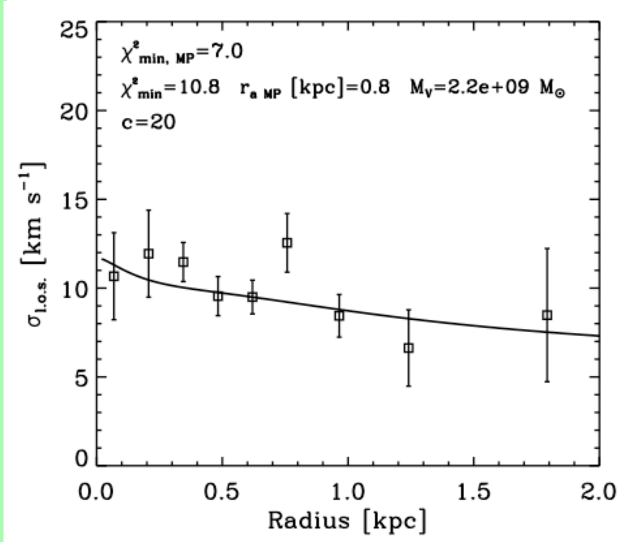


Excellent fit!

NFW

c=20





Nice fit but...

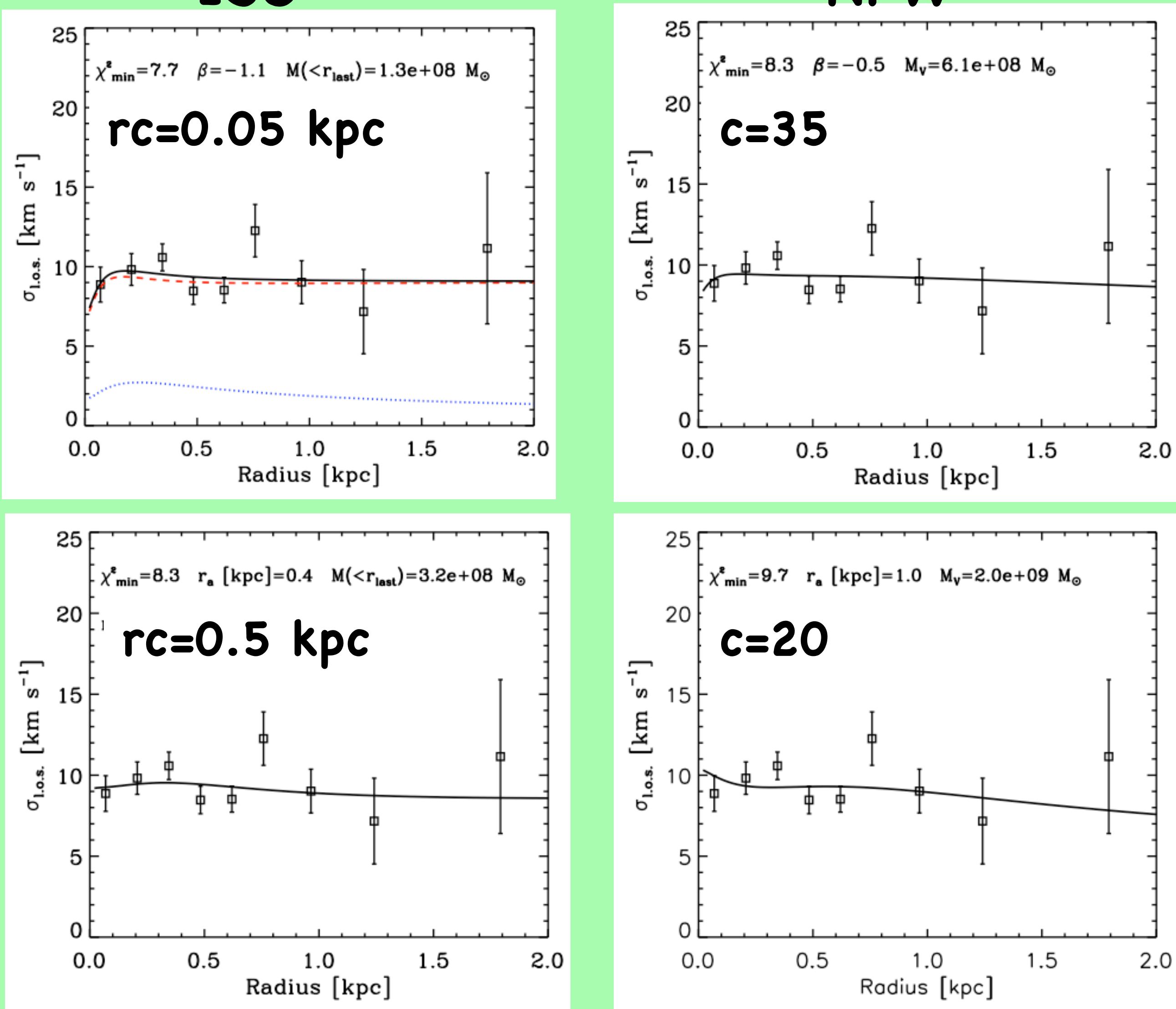
HR data (vel errors ~ 0.5 km/s) suggest a lower MR central dispersion => quality of fit for NFW profile gets worse (even for lower concentrations)

One component modeling: not possible to distinguish between DM profiles

ISO **NFW**

β constant

β OM



Results: modeling

- Two-components modeling helps relieving some degeneracies (useful to apply to other galaxies)
- ß Osipkov-Merrit models give very good fit:

  - Iso large core radius (0.5 kpc): excellent fit.

    $M(<r_{last}) = 3.4 \pm 0.7 \times 10^8 \, M_{sun}$

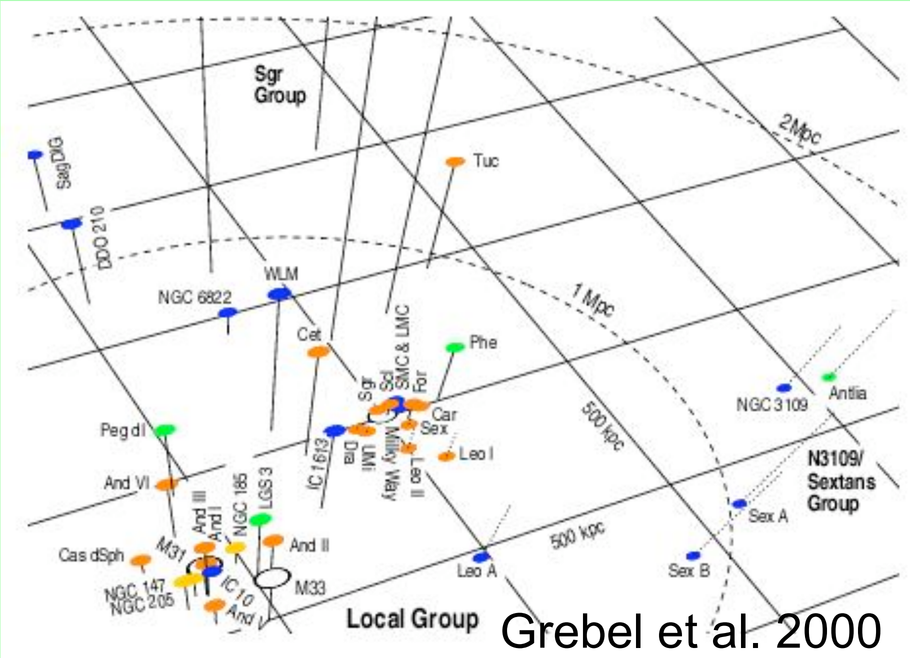
- Mass within last point well constrained (1 order of magnitude larger than previous measurements)

- $M/L = 158 \pm 33 \, (M/L)_\odot$ within 1.8 kpc

Some future prospects/plans

- How common multiple stellar components are? (e.g. not present in the Sextans & Carina dSphs…)
  - Extend similar observations to other dSphs
  - Models needed to understand why multiple stellar populations form (or do not), and possible role of environment
- Detailed mass determination of dSphs
  - Two-components modeling to be applied to other dSphs (next in line: Fornax dSph)

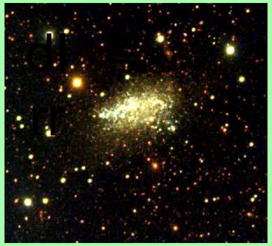
Some future prospects/plans:
The Local Group morphology-density relation



Grebel et al. 2000

dIrrs

dSphs



?

=>

(as from Mayer et al. 2001, 2006 models)

If dIrrs transformed into dSphs:

1) Common chemical properties between the ancient population of dIrrs and dSphs => CaT surveys of dIrrs

2) Presence of objects with intermediate properties (e.g. bars, rotation….) => extended kinematical surveys hopefully combined with better proper motion measurements