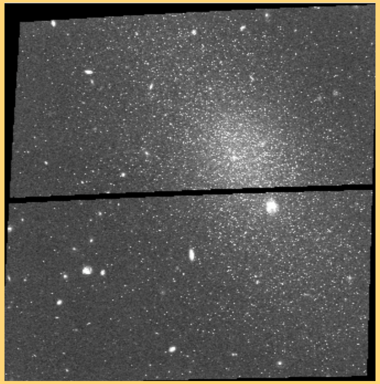
The Stellar Populations of dE galaxies in nearby Groups



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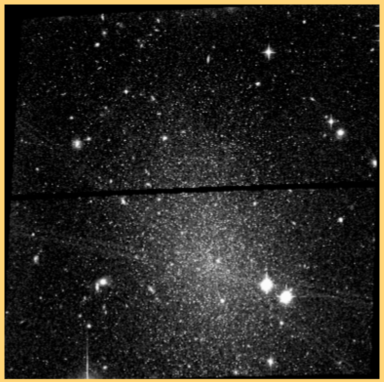
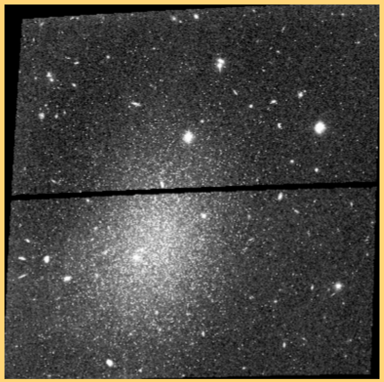
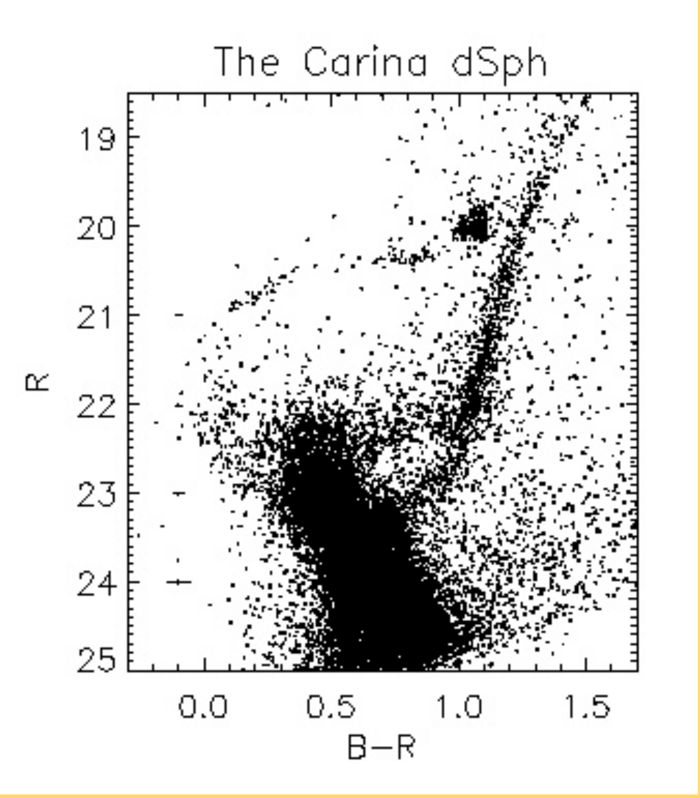




Background

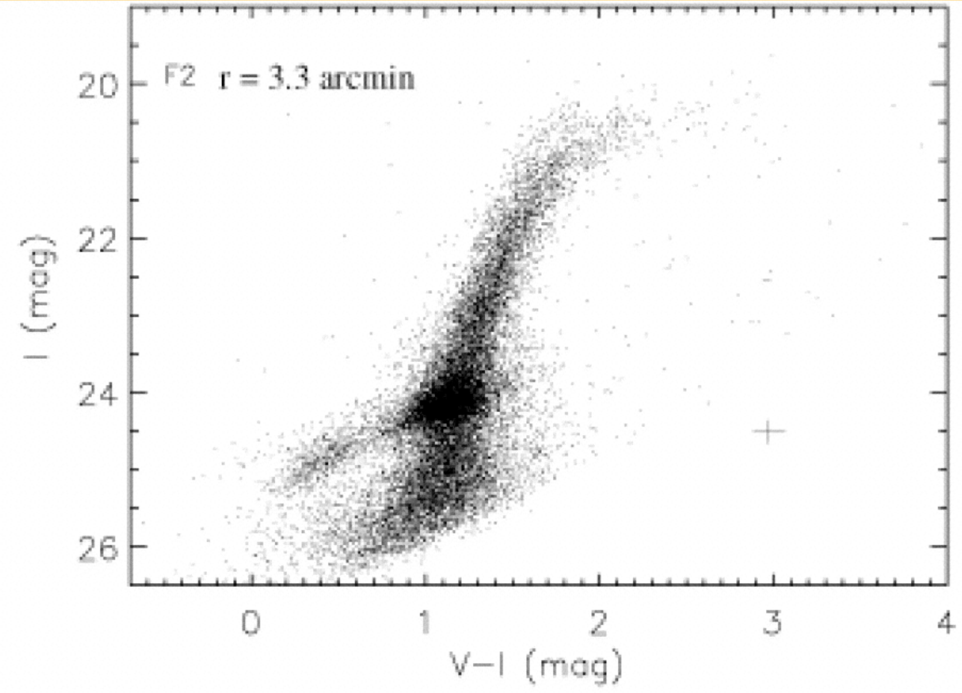


Carina data from Smecker-Hane et al. (1998) showing multiple episodes of star formation.

We have known for some time now that the dwarf Ellipticals (includes dwarf Spheroidals) of the Local Group show a *variety of star-formation histories*.

- For the Milky Way companions these range from basically single old stellar populations (*Ursa Minor*) through to systems like *Carina*, *Fornax* and *Leo I* which have had complex star formation histories, and contain stars as young as ~1 Gyr (or even less in the case of *Fornax*).
- Extended star formation is also evident in the M31 dE and dSph companions.

Background Continued…

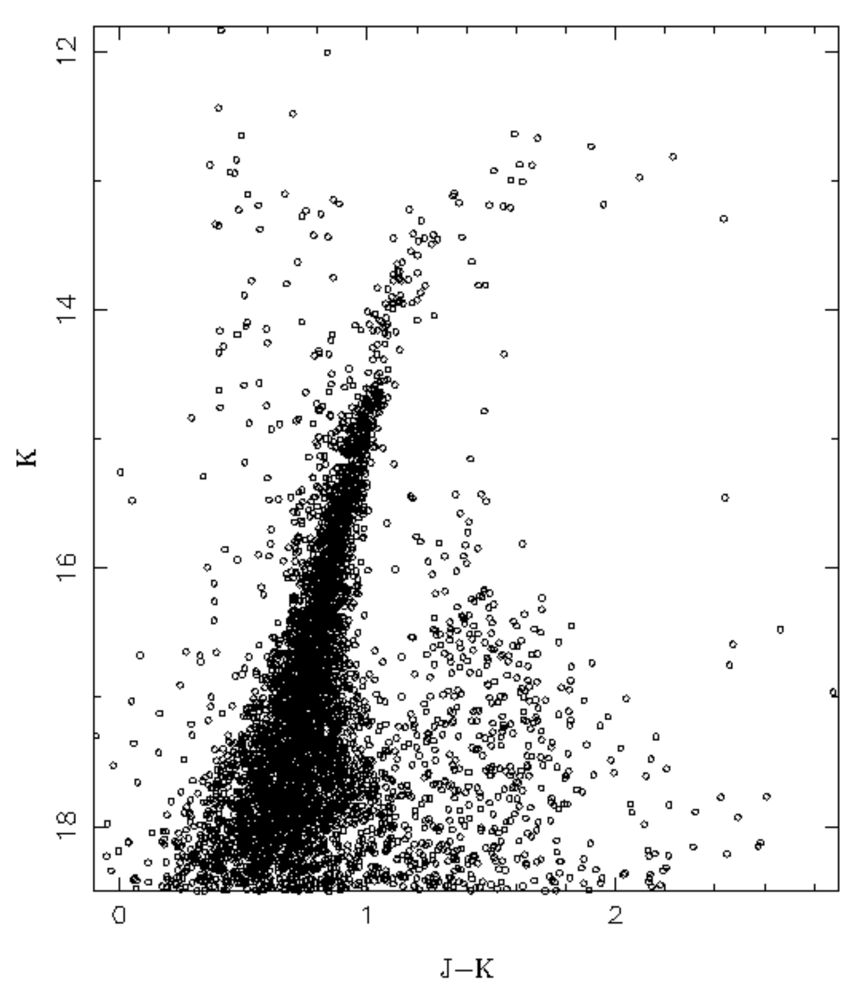


NGC 185 data from Butler & Martinez-Delgado (2005). Stars beyond the RGB tip (at I=20.3) come from the intermediate-age (1-10 Gyr) population. Many are carbon stars.

For the Galaxy's companions, the information on the star formation histories now comes from observations that reach below the main sequence turnoff(s).

But for the more distant systems, the evidence for intermediate-age populations comes primarily from the discovery that they contain upper-AGB stars – stars with enough mass to evolve to luminosities well above the RGB tip.

Background Continued…

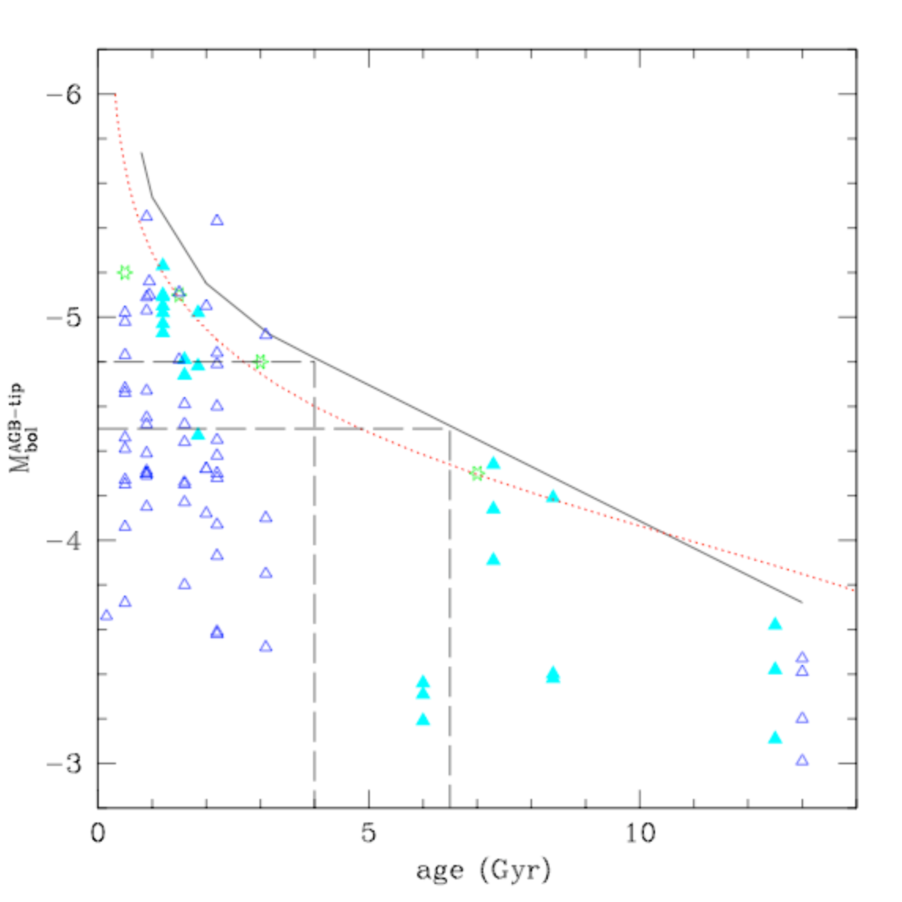


Fornax near-IR CMD from Saviane. Upper-AGB stars clearly visible above RGB tip at K=14.6

Provided the mean metallicity of the dE is below [Fe/H] ≈ −1.0,

- The luminosity of the brightest upper-AGB stars gives an indication of the epoch of the last episode of significant star formation, and
- The number of upper-AGB stars relative to the number of red giants gives a (first order) indication of the relative importance of the intermediate-age population.

Background Continued…



- For the MWG dSph companions, the ages inferred from the AGB-tip are consistent with the main sequence data.

For example, for Leo I M_{bol}(AGB) ≈ -5.1 is consistent with a 1-2 Gyr age for last substantial star formation.

(AGB-tip, age) relations from Rejkuba et al. (2006).

Do we understand what causes the variety of star formation histories seen among Local Group dEs?

In general, no (!) but ***environment****, as represented by, for example, proximity to a luminous galaxy, and the type of that galaxy, most likely plays a role in influencing the star formation history of these low-luminosity systems*.

- There is the well known *morphology-density* relation in which the majority (but not all !) of the isolated dwarf galaxies in the Local Group are (star-forming, gas-rich) *dIrrs*, not dEs.

- Similarly, for the Milky Way (and maybe M31?), generally the more distant dE/dSph companions have more prominent intermediate-age populations.

Clearly, if we want to understand the role of environment then the next step is to study the stellar populations of dEs in groups beyond the Local Group.

Fortunately the nearest groups provide a variety of different environments…

Sculptor Group – This is a loose aggregation of galaxies ranging in distance from ~1.5 to ~4 Mpc. It contains a half dozen or so low luminosity early-type systems.

M81 and *Cen A* groups – These are denser, more compact groups at distances of ~3.5 to 4 Mpc. Both groups contain a dozen or more low luminosity early-type systems.

The dSph systems in these groups cover a range of internal (absolute magnitude, size, etc) and external (distance from nearest large galaxy, local galaxy density) properties.

We are carrying out a program to study in detail the stellar populations of the dE galaxies in these groups using:

- HST ACS/WFC and existing ‘snapshot’ data for distances and metal abundances,
- Gemini-N NIRI and ESO VLT ISAAC data for upper-AGB populations,
- ATCA and Parkes observations (Sculptor, Cen A only) for neutral hydrogen detections or limits.

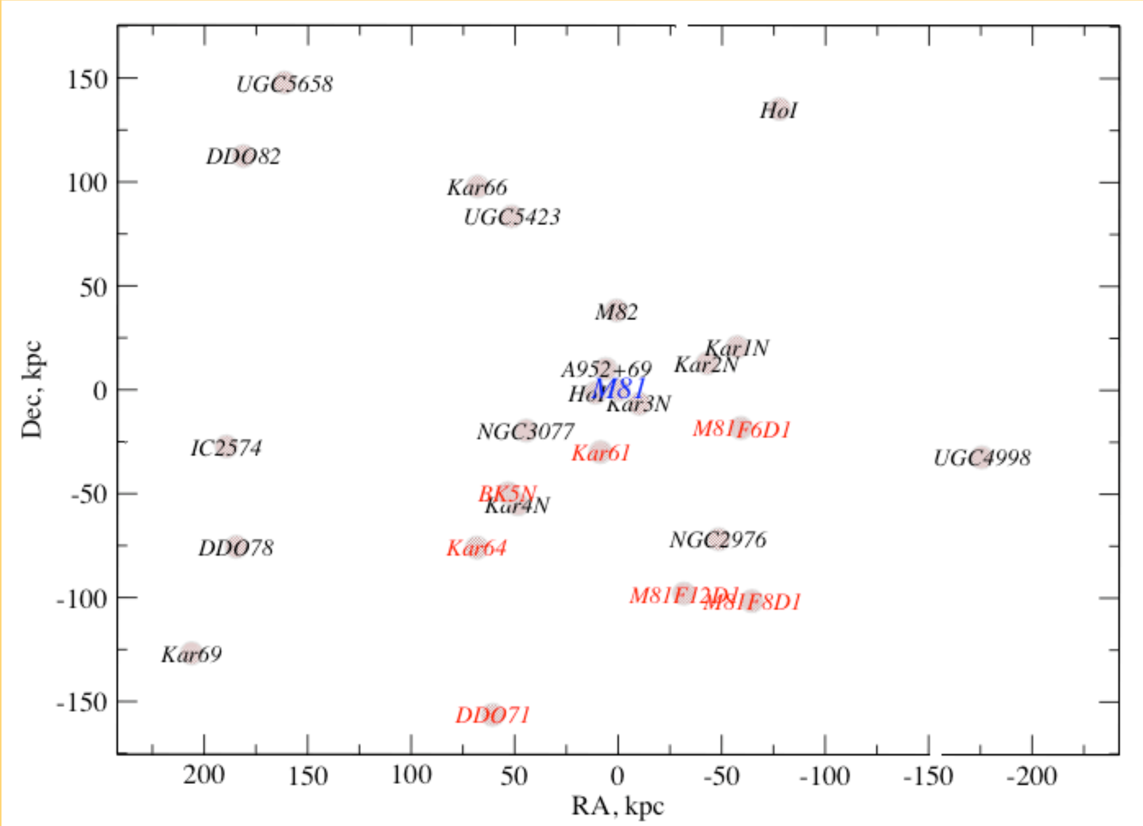
Collaborators:

M81 – Armandroff (NOAO), Caldwell (CfA), Coleman (RSAA/Heidelberg) and Prior (RSAA student)

Scl and Cen A – Binggeli (Basel), Jerjen (RSAA), Rejkuba (ESO), Zoccali (PUC) and Bouchard (RSAA student).

Concentrate today on the M81 group:

(Marina Rejkuba will discuss the Cen A group tomorrow)



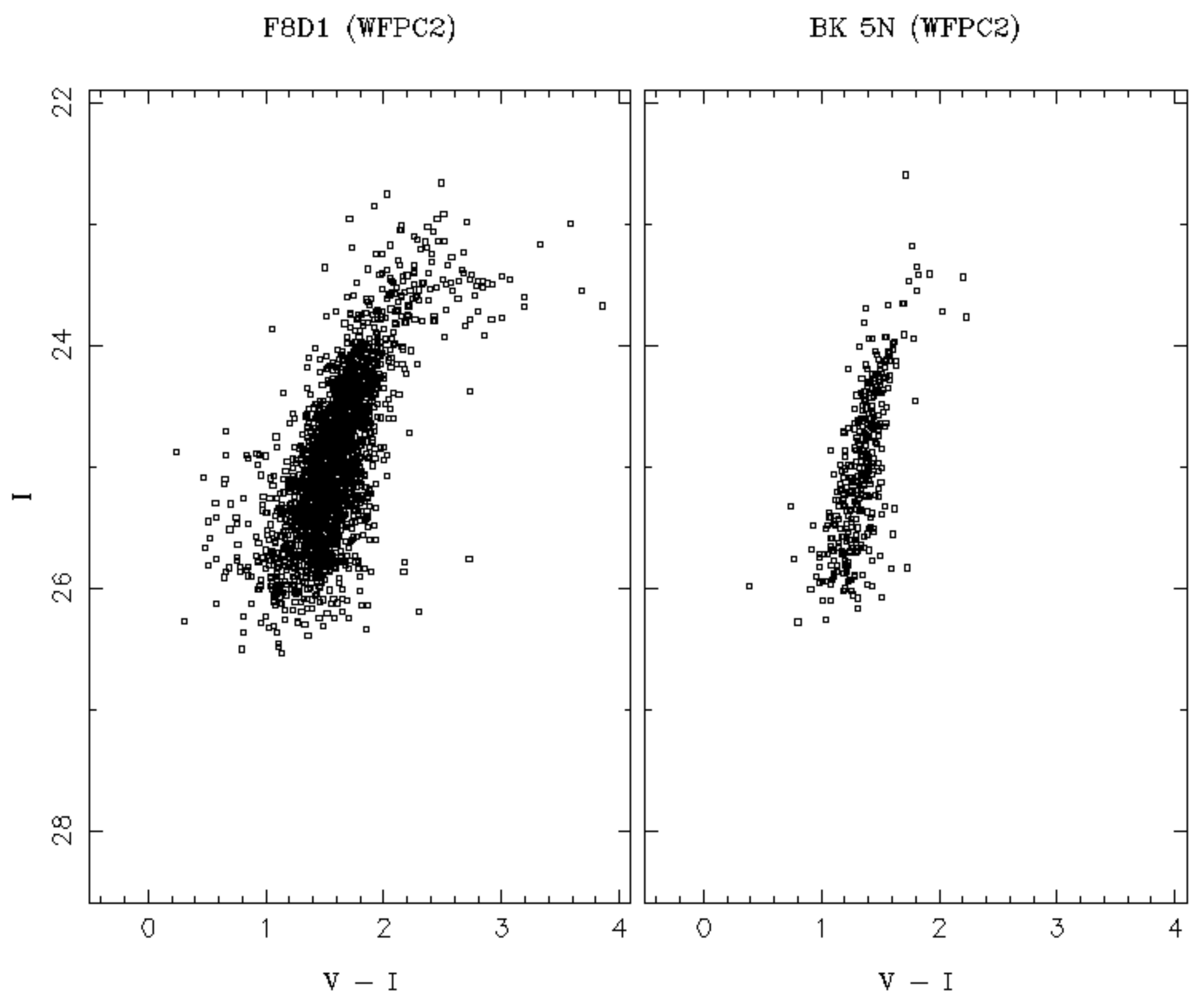
M81 group known to have had a number of relatively recent interactions. ~20 galaxies within 200kpc projected radius of M81 (cf. ~4 for the Milky Way). dEs, dIrrs, peculiar galaxies (M82, 3077) and small spirals all found.

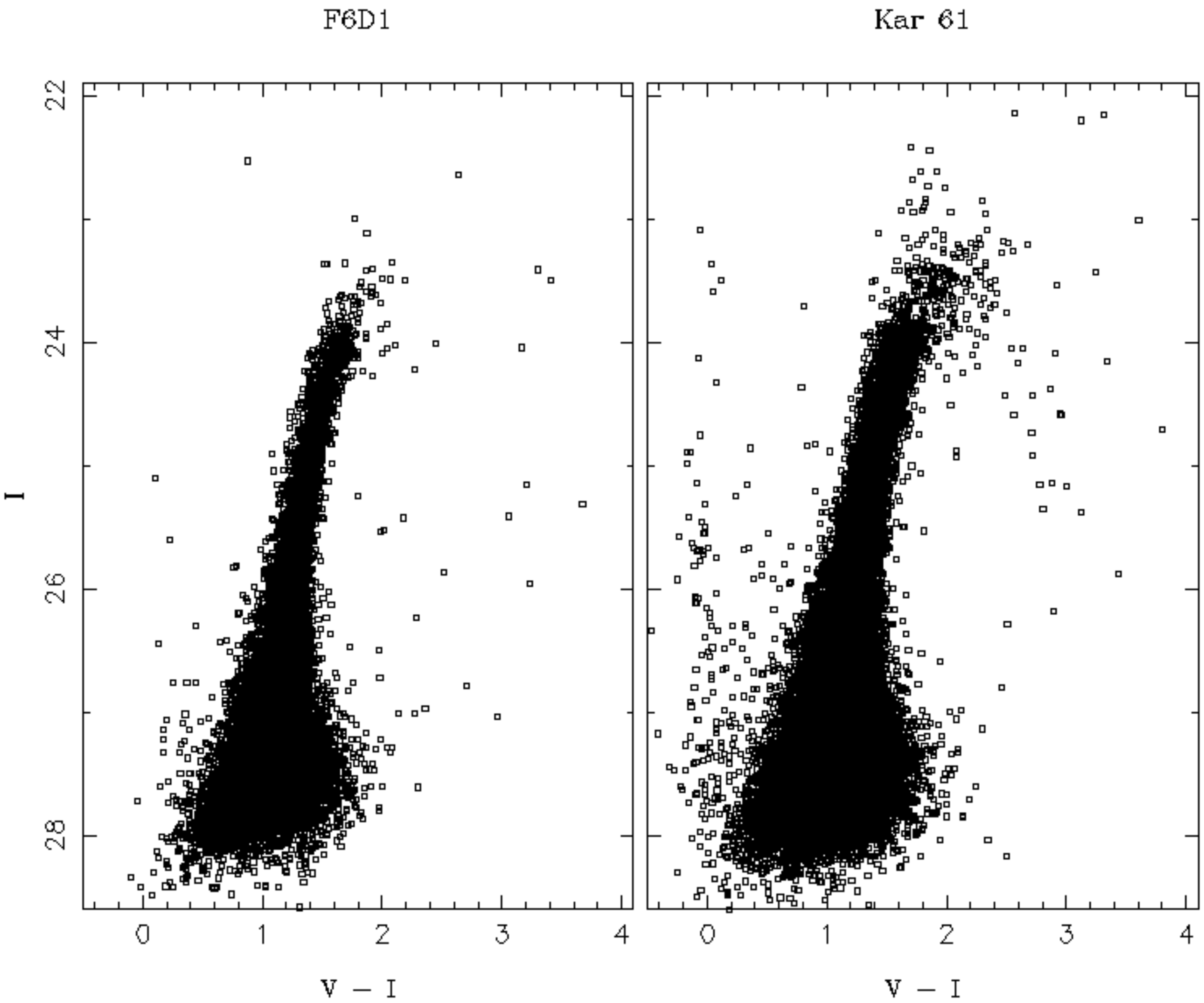
Specifically discuss new ACS/WFC data for 5 M81 group dEs together with older WFPC2 data (Caldwell et al. 1998) for 2 more:

Kar 61 (KDG 61, [KK98] 081)	$M_V = -13.5$	30kpc
F6D1 ([FM2000] 1)	$M_V = -11.7$	60kpc
Kar 64 (UGC05442, KDG 64, [KK98] 085)	$M_V = -13.6$	100kpc
F12D1 ([KK98] 077)	$M_V = -13.7$	105kpc
DDO71 (UGC05428, KDG 63, [KK98] 083)	$M_V = -13.4$	170kpc

The ACS/WFC data for each dE consists of a total of 17200s with the F606W filter (wide-V) and 9000s with the F841W filter (wide-I). The long total integration times were possible because of the location of the M81 group in the continuous viewing zone (~x2 increase in efficiency).

The Caldwell et al. (1998) data are for F8D1 (-14.2, 120kpc) and BK 5N (-11.3, 75kpc).


F8D1 (WFPC2)
BK 5N (WFPC2)
I
V − I
22
24
26
28
0
1
2
3
4


F6D1
Kar 61
I
22
24
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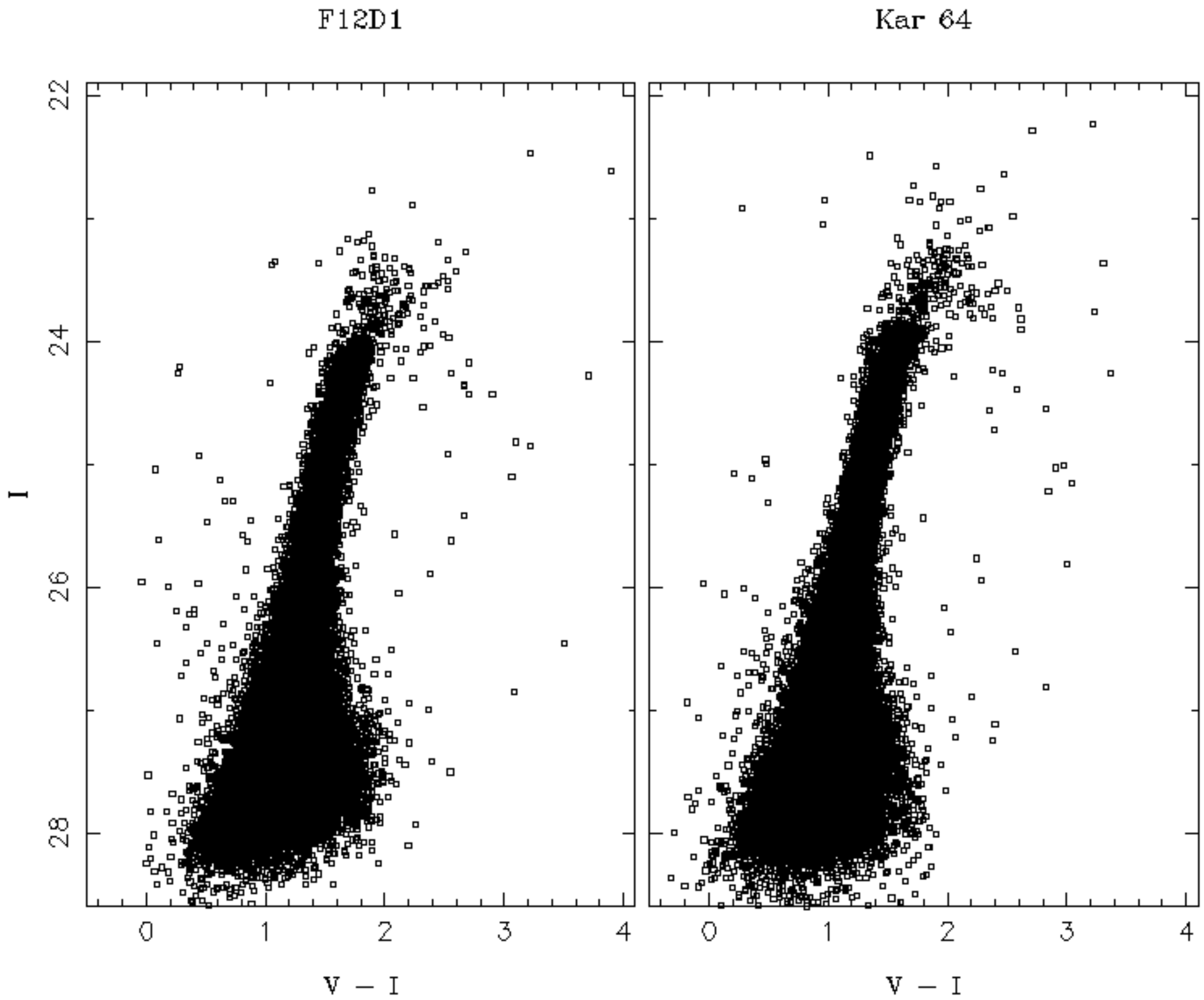
V − I


F12D1
Kar 64
I
22
24
26
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1
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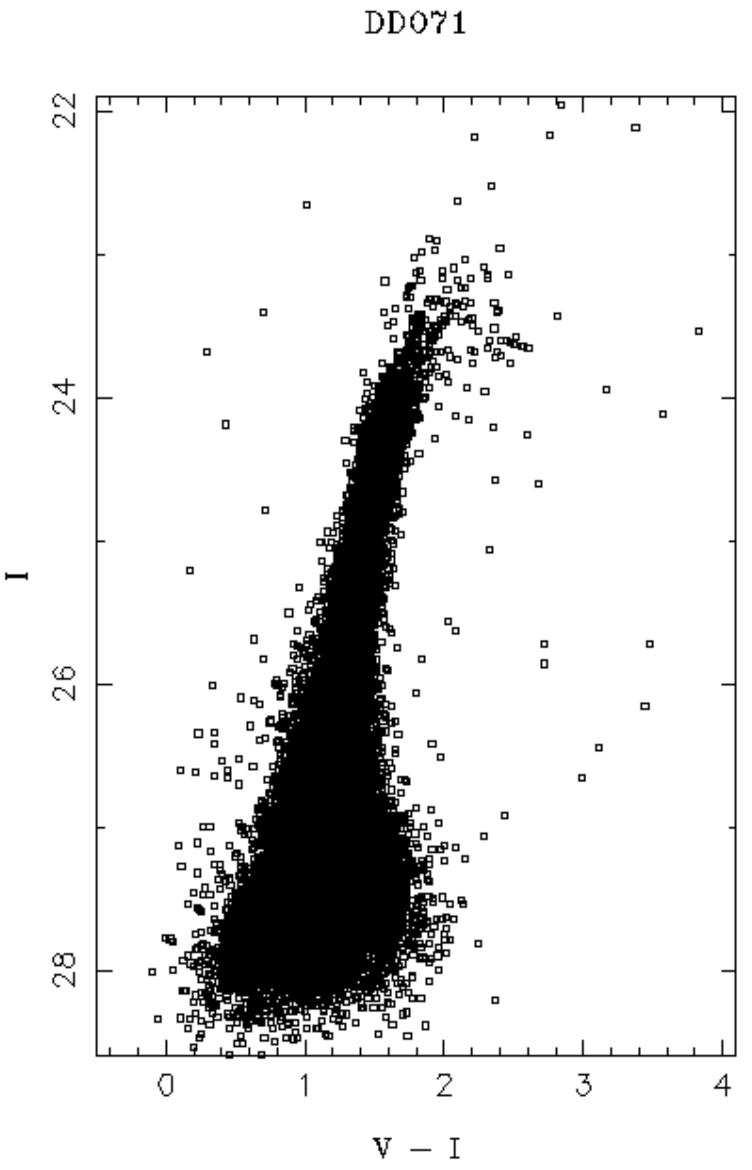
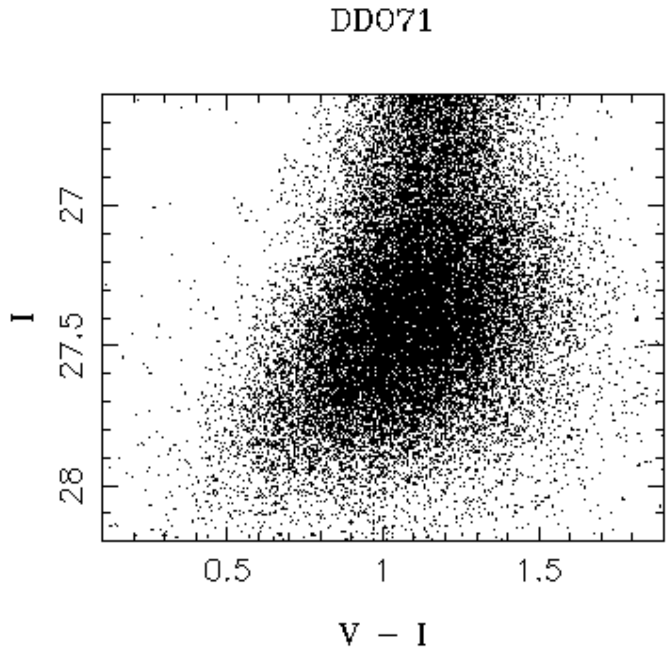
V − I
V − I


DDO71
22
24
26
28
I
0
1
2
3
4
V − I


DDO71
27
27.5
28
I
0.5
1
1.5
V − I

ACS data

In all five galaxies we are clearly seeing a red clump population near the limit of the data at $I \approx 27.5$ ($M_I \approx -0.3$). Given the low metallicities of the dEs, this may indicate a substantial population of stars somewhat younger than the Galactic globular clusters.

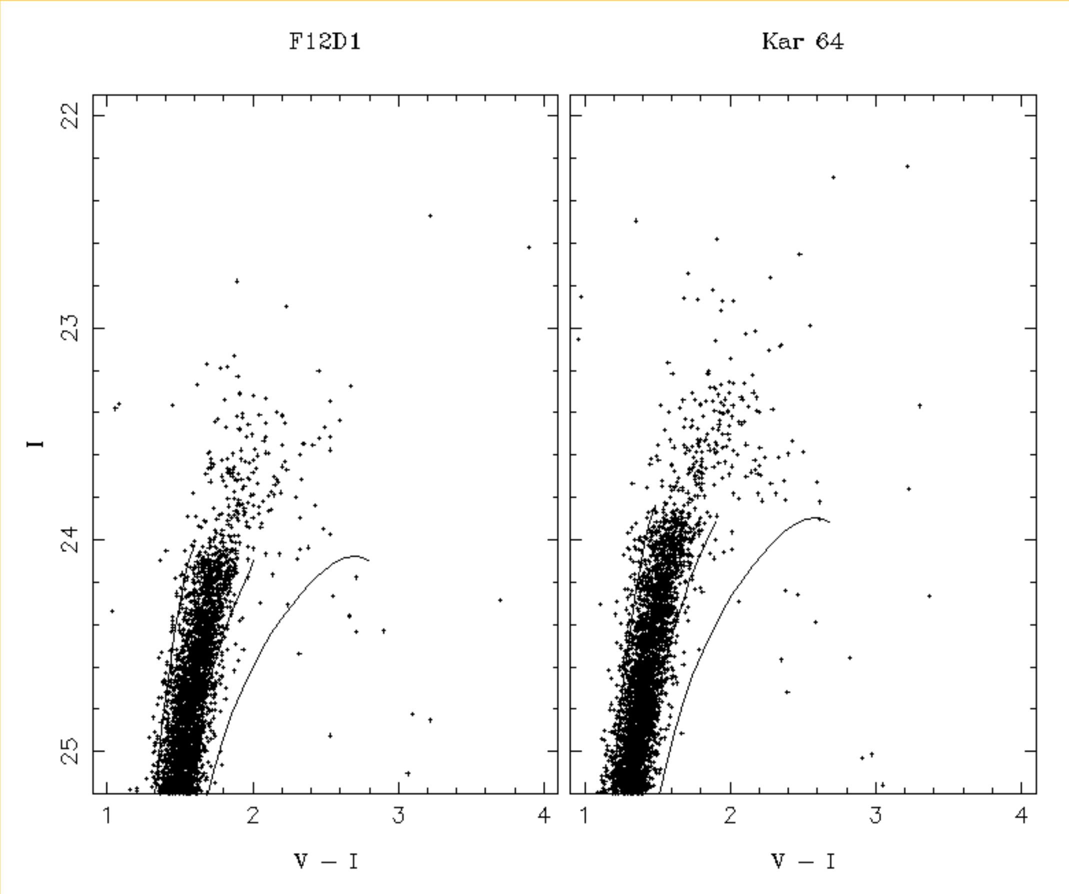
- However, to understand the implications we need to do population modelling of the colour-magnitude diagrams (CMDs), and to do that we need to establish completeness corrections and errors as a function of magnitude and location. This requires a lot of artificial star tests which we have not completed yet.

- Concentrate on the upper part of the CMDs where the errors are small and the completeness corrections negligible: determine *distances, metallicity estimates and the upper-AGB populations.*

Distances

- Using the I magnitudes of the tip of the red giant branches, the mean distance for all 7 dEs is 3.70 Mpc, with a 1σ dispersion of only ±140 kpc, consistent with that expected just from the errors.
- The difference in modulus between the 'nearest' and 'farthest' galaxies is only 0.24 ± 0.12 mag, so it is only at the 2σ level that rule out all galaxies being at the same distance!
- Clearly all 7 dEs are within the 'core' of the group.

Abundances

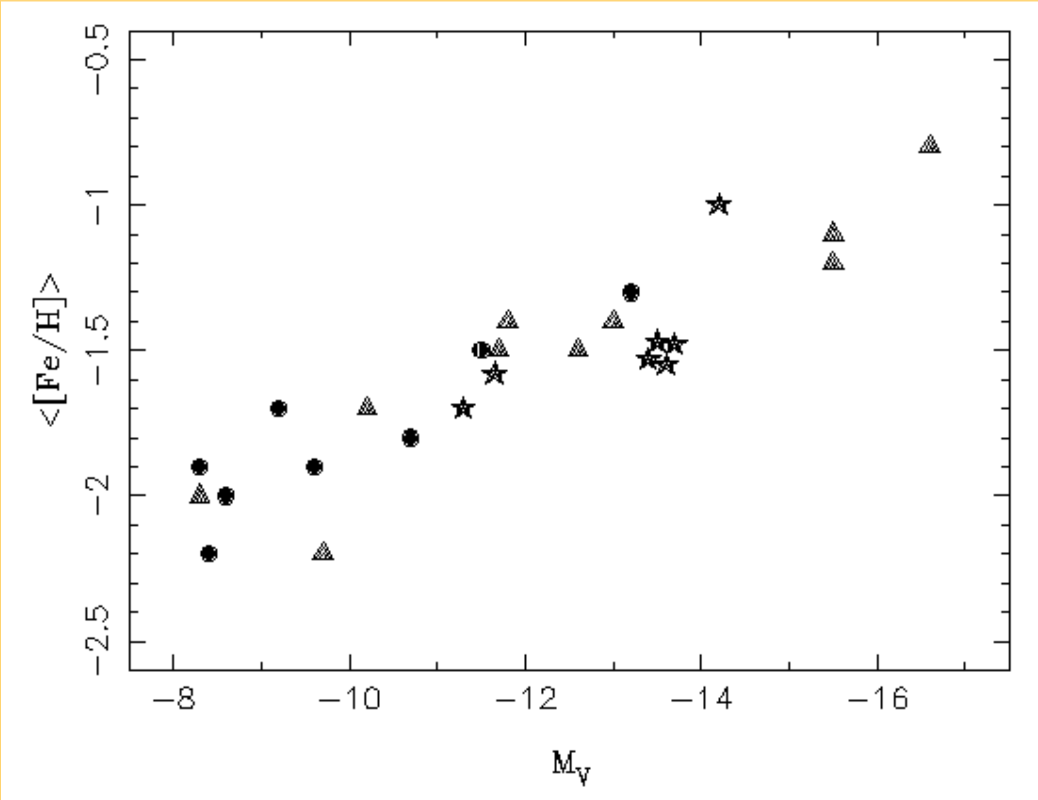


Once the distances are known, *mean abundance estimates* can be derived from the mean colour of the RGB compared to the colours of standard Galactic globular cluster giant branches.

This estimate is strictly a lower limit as the RGB of a younger population is bluer at fixed abundance.

Giant branches shown are for M15 ([Fe/H] = -2.17, NGC 1851 (-1.36) and 47 Tuc (-0.71).

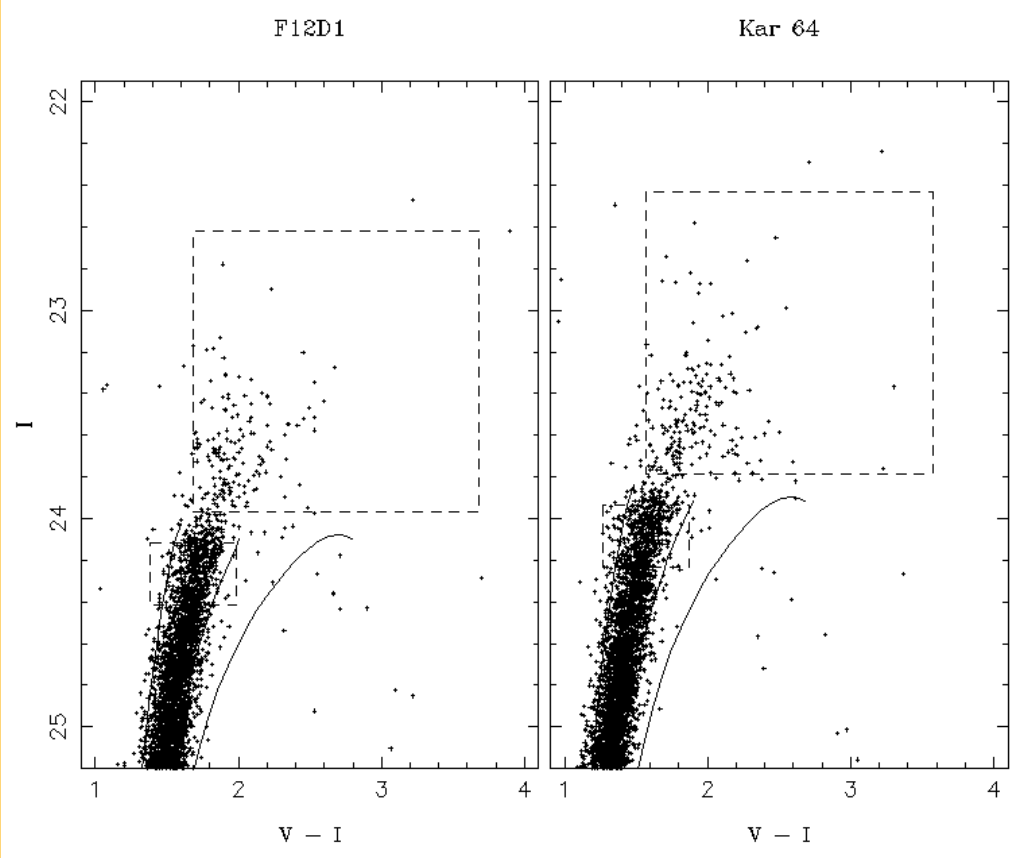
Abundances



Star symbols are M81 group objects, circles are MWG companions, triangles are M31 companions.

- *In general the M81 dEs fall-in with the Local Group objects in the metallicity - absolute magnitude diagram.*
- Not really too surprising since the existence of a mass-metallicity relation for dEs seems to be a universal phenomenon (equivalent to the colour-magnitude relation for luminous early-type galaxies).

Upper-AGB populations



Upper-AGB box based on the population seen in F8D1 ($-4.15 > M_I > -5.5$ and $1.5 < (V\text{-}I)_0 < 3.5$).
RGB box is 0.3mag wide in I.

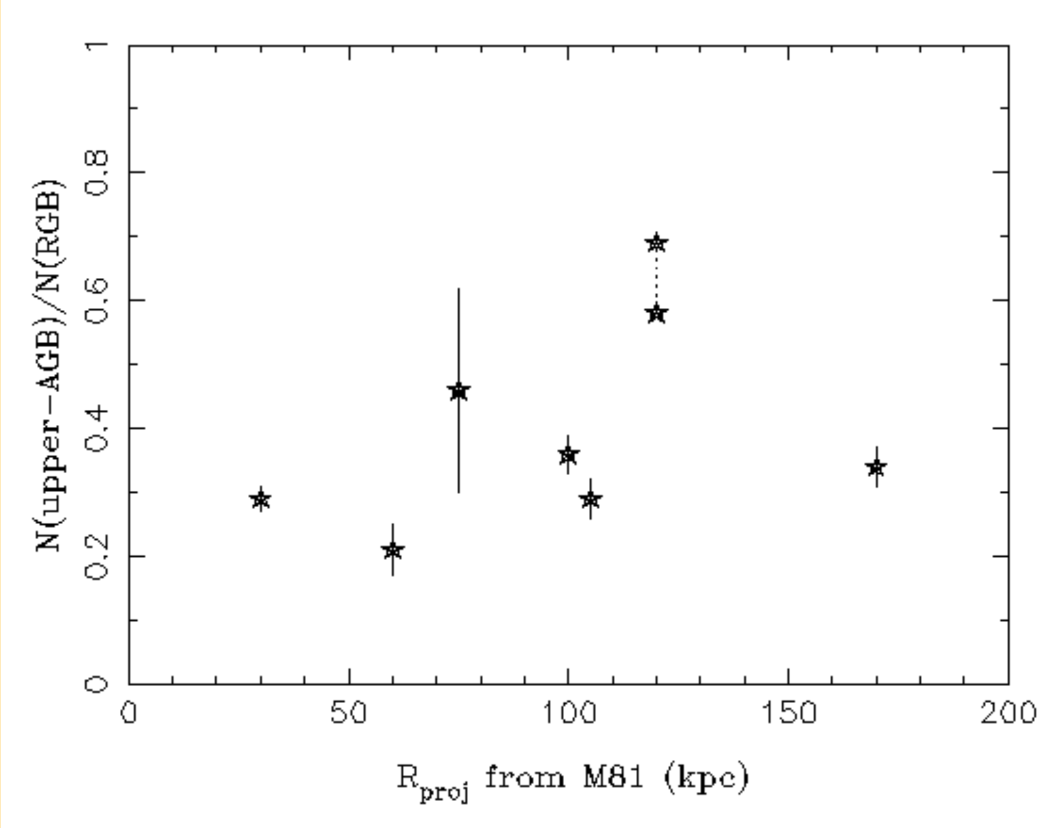
First properties to look at are simple quantities such as:

(a) the number of upper-AGB stars relative to the number of red giants near the tip, and

(b) the mean luminosity of the 3 brighest upper-AGB stars.

(c) the bolometric luminosity functions.

Upper-AGB populations

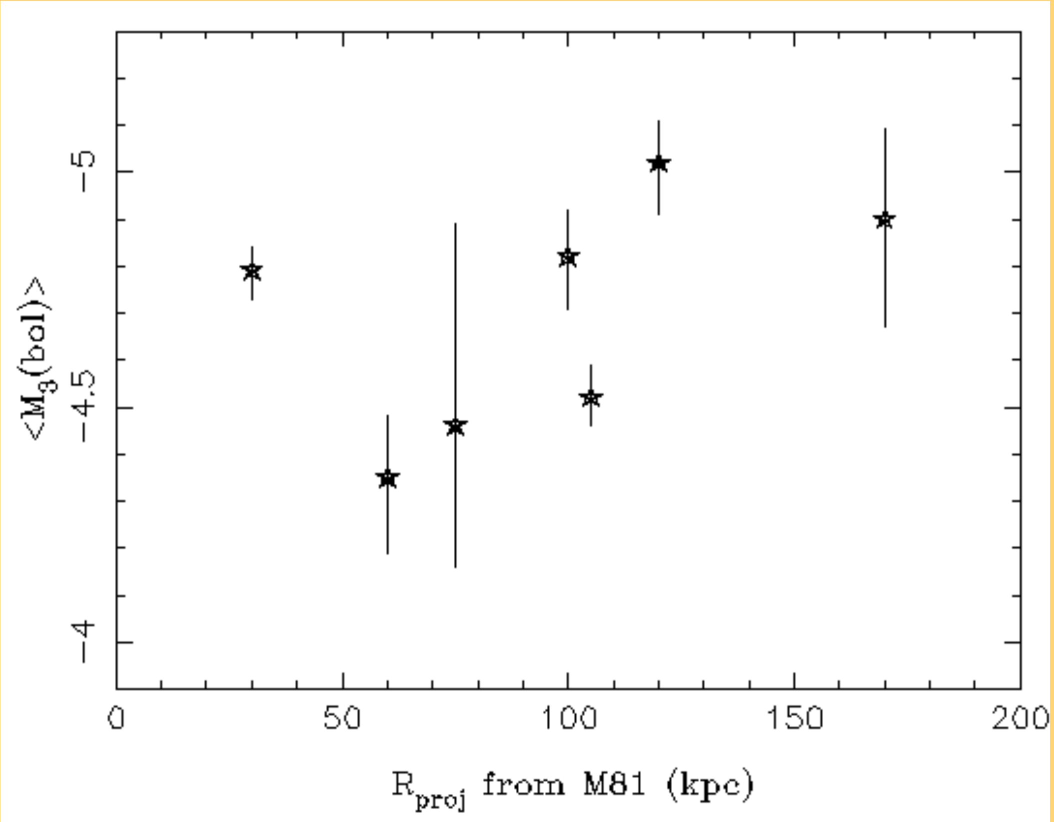


Error bars are assume Poission statistics (there are only few stars in BK 5N). Upper point for F8D1 has no correction for metal-rich population, lower point assumes metal-rich population is entirely old.

- *No obvious correlation with projected distance from M81*, nor is there any indication of any dependence on M_V or [Fe/H].

- Based on Maraston's evolutionary models, for a simple model consisting only of two discrete populations, one of fixed intermediate-age (IA) and one old (13 Gyr), a ratio of ~0.3 corresponds to the IA population making up ~15% of the total for IA=2 Gyr to ~60% of the total for IA=5 Gyr (full population synthesis models needed).

Upper-AGB populations



Vertical lines show brightest and third brightest M_{bol} values. Once again note there are only few stars in BK 5N, which gives a large uncertainty.

- *No obvious correlation with projected distance from M81*, nor is there any indication of any dependence on M_V or [Fe/H].

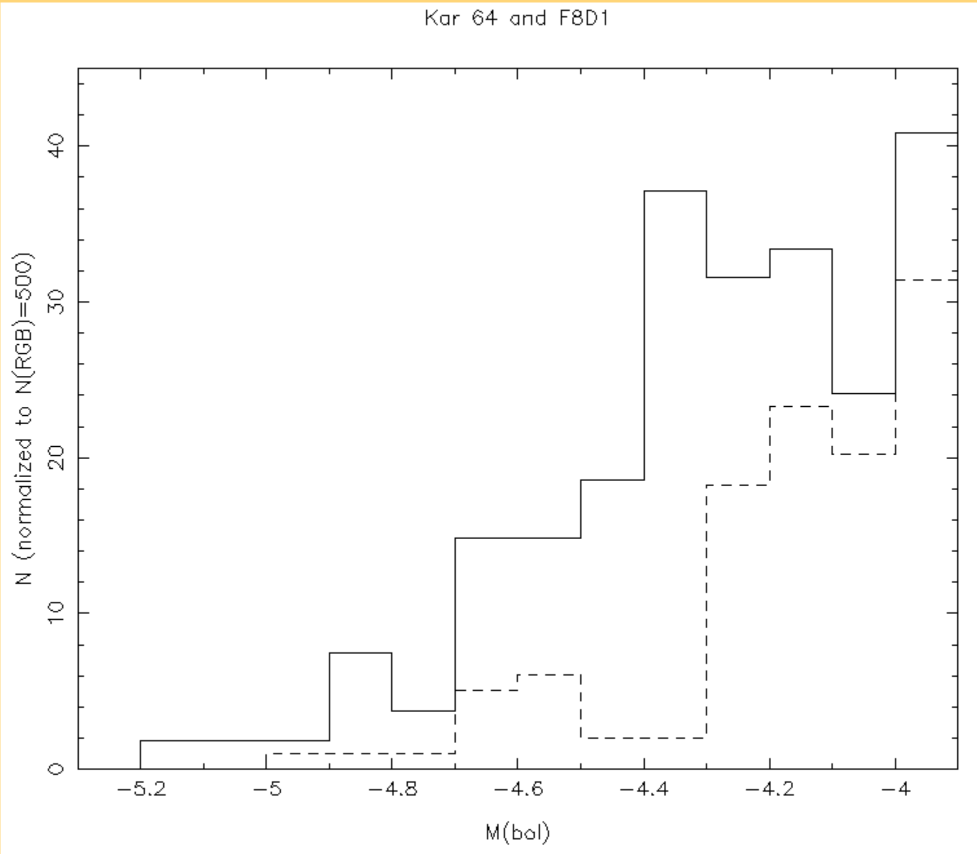
- Inferred epochs of last significant star formation:

F8D1	2.5	Gyr
DDO71	3.5	Gyr
Kar 61	4	Gyr
Kar 64	4	Gyr
F12D1	6.5	Gyr
BK5N	7?	Gyr
F6D1	8	Gyr

The diversity in these values is similar to what is seen in the Local Group.

Upper-AGB populations

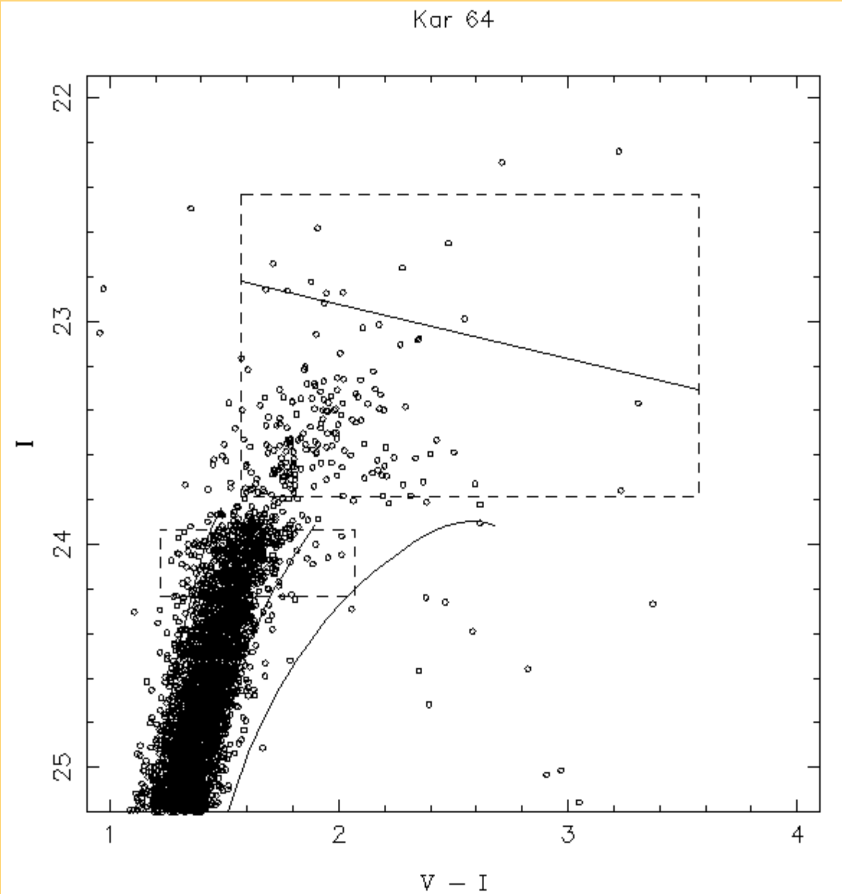
One further question is whether there is any obvious structure in the upper-AGB bolometric LFs. For most of the sample, the answer is 'no'. The possible exception is Kar 64 which has a 'feature' at $M_{bol} \approx -4.6$.



AGB numbers have been normalized to N(RGB)[tip, tip+0.3] = 500. Kar 64 is the dashed line, F8D1 is the solid line

Upper-AGB populations

This 'feature', which nominally would correspond to enhanced star formation about ~6 Gyr, is also evident in the c-m diagram….



Solid line corresponds to M_{bol} = -4.6

Conclusions (1)

- Like the Local Group dEs and dSphs, the M81 group dEs apparently show a variety of star formation histories (SFH).

- Although the sample of M81 group dEs studied is not complete, none of the 7 objects studied so far show similarities to Local Group dEs like Ursa Minor and Tucana, which have dominant old (age > 10 Gyr) populations. *"Classic" dEs (meaning objects consisting of a single old stellar population, cf: Baade Pop II) are apparently rare objects.*

- There are no clear dependencies of SFH/intermediate-age pops on distance from M81 (cf. the Milky Way dSphs). This is perhaps not surprising given the level of interactions in the core of the M81 group.

- Stay tuned for full population synthesis models of the ACS data…